ARMY TM 5-805-9
AFJMAN 32-10137
(FORMERLY AFM 88-20)
NAVY NAVFAC DM-3.14
30 December 1983

+--+ ¦ CCB Application Notes: ¦

¦ 1. Character(s) preceded & followed by these symbols (+ +) or (+ +) ¦
¦ are super- or subscripted, respectively.
¦ EXAMPLES: 42m+3+ = 42 cubic meters
¦ CO+2+ = carbon dioxide

¦ 2. All degree symbols have been replaced with the word deg.

¦ 3. All plus or minus symbols have been replaced with the symbol +/-. ¦

¦ 4. All table note letters and numbers have been enclosed in square
¦ brackets in both the table and below the table.

¦ 5. Whenever possible, mathematical symbols have been replaced with
¦ their proper name and enclosed in square brackets.

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POWER PLANT ACOUSTICS

DEPARTMENTS OF THE ARMY, THE AIR FORCE, AND THE NAVY DECEMBER 1983

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POWER PLANT ACOUSTICS

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This manual supersedes TM 5-805-9, 14 December 1968 and together with TM 5-805-4, rescind DA Forms 3452-1-R, 3452-2-R, 3452-3-R, 3452-4-R, 3452-5-R, 3452(RE)-6-R, 3452(RE)-7-R, 3452(T)-8-R, 3452(T)-9-R, 3452-10-R, 3452-1-R, 3452-12-R, and 345213-R, Dec 68 and DA Forms 3452-14-R, 3452-15-R, 3452-16-R, 3452-17-R, 3452-18-R, 3452-19-R, and 3452-20-R, August 1970.

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CHAPTER 1

SCOPE OF MANUAL

1-1. Purpose and scope.

This manual provides noise control data and analysis procedures for design and construction of diesel, gas, and gas turbine engine facilities at military installations in the continental United States (CONUS) and for U. S. military facilities around the world. The data and procedures are directed primarily toward the control of noise from engine-driven electric generators but are equally appropriate for any power system using reciprocating or turbine engines. This manual applies to all new construction and to major alterations of existing structures. U.S. military facilities that require higher standards because of special functions or missions are not covered in this manual; criteria and standards for these exceptions are normally contained in design directives for the particular facilities. If procedures given in this manual do not provide all the functional and structural needs of a project, recognized construction practices and design standards can be used.

1-2. General contents.

This manual presents a review of applicable sound-and vibration-level criteria, sound level data for reciprocating- and turbine-type engines driven by gas and liquid fuels, a basic approach for evaluating an engine noise problem, procedures for controlling engine noise and vibration, and examples that illustrate the entire system analysis. The sound level data quoted in the manual are based on measurements of more than 50 diesel and natural gas reciprocating engines and more than 50 gas turbine engines. Almost all of the leading manufacturers are represented in the collection of data. The sound level data given in the manual are 2 dB higher than the average of the measured sound levels in order to include engines that are slightly noisier than the average. This inclusion means that designs based on the data and methods used in the manual will provide design protection for approximately 80 to 90 percent of all engines in any random selection. The few remaining engines may have sound levels of possibly 1 to 5 dB above the values used here. Sound power level data are quoted for the engines, but the procedures in the manual show how these data are converted to the sound pressure levels that are needed. The term "engine," as used in the manual, may be construed to represent "engine-generator" or "engine-generator set" when used in the larger sense to include both the driver and the driven equipment.

1-3. Typical problems of uncontrolled noise.

The noise of a typical engine-driven electric generator is great enough that it can cause some loss of hearing to personnel working in the same room with the engine, and the noise radiated outdoors by an unenclosed engine can be heard a mile away and can disturb the sleep of people living a half-mile away--if adequate noise control measures are not taken. These two extremes show the range of the problems that may be encountered with a power plant, and they illustrate the range of noise problems covered by this manual. A few specific examples are listed and discussed briefly.

a. Hearing damage to engine operator. Human hearing loss represents the most serious aspect of the engine noise problem. A power plant operator who regularly spends 8 hours per day inside an engine room, with no acoustic enclosure and no ear protection, will experience some degree of noise-induced permanent hearing loss over a period of time in that noise field. Military regulations prohibit such noise exposures, and this manual recommends separate control rooms for such problems.

b. Speech interference. Most of the "intelligibility" of the voice is contained in the middle and upper frequencies of the total audio range of hearing. When an interfering noise has a frequency spread that covers the middle and upper portion of the total audio range, it has the potential of "masking" the speech sounds. If the interfering noise is not very loud, a talker overcomes the masking effect by talking louder. If the interfering noise is very loud, the talker must shout and the listener must move close to hear and understand the spoken message. If the interfering noise is too loud, the voice is not strong enough to overcome the masking effect--even at short distances while the speaker is shouting almost into the listener's ear. In such high noise levels, speech communication becomes difficult, tiring, and frustrating, and facts may be distorted when the listener erroneously interprets the imperfectly heard speech. Long sentences are fatiguing to the talker, and long or unfamiliar words are not understood by the listener. Engine room noise usually discourages long sentences, unfamiliar terms, and complex conversations. Quieter surroundings are required for lengthy, precise speech communication. The manual addresses this problem.

c. Interference with warning signals. In some noisy work areas, warning bells or horns and announcement or call systems are turned up to such high levels that they are startling when they come "on" abruptly. In fact, because they must penetrate into all areas of a noisy plant, they are so loud they "hurt" the ear when a listener happens to be near the signal source. On the other hand, a "weak" bell or call might not be heard at all. Some auxiliary paging and warning systems are suggested later in the manual.

d. Difficulty of telephone usage. The noise levels inside most engine rooms completely preclude telephone usage. For emergency use as well as for routine matters, a quiet space satisfactory for reliable telephone usage must be provided within or immediately adjoining an engine room. The acoustical requirements for such a space are covered in the manual.

e. Noise intrusion into nearby work spaces. Different types of work spaces require different types of acoustical environments. The maintenance shop beside a diesel engine room can tolerate a higher background noise than the offices and meeting rooms of the main headquarters of a base. It is possible to categorize various typical work areas according to the amount of background noise considered acceptable or desirable for those areas. A schedule of "noise criteria" provides a range of noise levels considered appropriate for a range of typical work spaces, and the design portion of the manual indicates the methods of achieving these noise criteria, relative to engine-produced noise. Engine noise is accepted as a necessary part of the power plant, but this noise is unwanted almost everywhere outside the engine room--hence, the emphasis on adequate noise reduction through architectural and engineering design to bring this noise down to an innocuous, unintruding "background" in those areas requiring controlled degrees of quietness.

f. Community noise problems. Rest, relaxation, and sleep place severe requirements on the noise control problem. Whether the base barracks or onsite housing or slightly hostile off-base neighbors control the design, the need for relatively quiet surroundings is recognized. The noise criteria and acoustic designs provided by the manual are aimed at achieving the background noise levels that will permit rest, relaxation, and sleep in nearby housing or residential areas.

g. Summary. These illustrations encompass the goals of this manual. In varying degrees, any noise problem encountered will involve hearing preservation, speech communication, annoyance, or noise intrusion. To a high degree, such problems can be evaluated quantitatively; practical and successful solutions can be worked out with the aid of the guidelines and recommendations presented in the manual.

1-4. Cross reference.

The manual "Noise and Vibration Control for Mechanical Equipment" (TM 5-805-4/AFM 88-37/NAVFAC DM-3.10), hereinafter called the "N&V" manual, is a complemental reference incorporating many of the basic data and details used extensively in this manual. (See app. B for additional references and app. C for related publications.)

CHAPTER 2

SOUND ANALYSIS PROCEDURE

2-1. Contents of chapter.
This chapter summarizes the four basic steps for evaluating and solving an engine noise problem. The steps involve sound level data for the source, sound (and vibration) criteria for inhabited spaces, the fundamentals of sound travel (both indoors and outdoors), and knowledge and use of sound (and vibration) treatments to bring the equipment into conformance with the criteria conditions applicable to the work spaces and neighboring areas. Much of this material is discussed in detail in the N&V manual, but brief summaries of the key items are listed and reviewed here. Special noise- and vibration-control treatments (beyond the normal uses of walls, structures, and absorption materials to contain and absorb the noise) are discussed in chapter 3, and examples of the analysis procedure are given in chapter 4.

2-2. General procedure.

In its simplest form, there are four basic steps to evaluating and solving a noise problem. Step 1 requires the estimation or determination of the noise levels produced by a noise source at the particular point of interest, on the assumption that no special acoustic treatment is used or required. Step 2 requires the establishment of a noise level criterion considered applicable for the particular point of interest. Step 3 consists of determining the amount of "excess noise" or the "required noise reduction" for the problem. This reduction is simply the algebraic difference, in decibels, between the noise levels produced by the equipment (step 1 above) and the criterion levels desired for the region of interest (step 2 above). Step 4 involves the design or selection of the acoustic treatment or the architectural structure that will provide the required noise reduction (step 3 above). This basic procedure is carried out for each octave frequency band, for each noise source if there are several sources, for each noise path if there are several possible paths, and for each point of interest that receives the noise. The basic procedure becomes complicated because of the multiplicity of all these factors. The ultimate success of the design depends largely on devising adequate practical solutions, but it also requires that a crucial noise source, path, or receiver has not been overlooked. Additional details that fall under these four steps follow immediately.

a. Step 1, source data.
(1) The sound power levels (PWLs) of the engine noise sources are given below in paragraphs 2-7 and 2-8. Sound pressure levels (SPLs) or sound power levels of some auxiliary sources may be found in chapter 7 of the N&V manual, or may have to be obtained from the literature or from the equipment manufacturers.

(2) Detailed procedures for converting PWL data to SPL data and for estimating the SPL of a source at any receiver position of interest indoors or outdoors are given in chapter 5 and 6 of the N&V manual.

(3) Where several noise sources exist, the accumulated effect must be considered, so simple procedures are given (Appendix B of the N&V manual) for adding the contributions of multiple noise sources by "decibel addition."

b. Step 2, criteria.

(1) Applicable criteria are discussed in the N&V manual (chap. 3 for sound and chap. 4 for vibration) and are summarized in paragraphs 2-3 and 2-4 below for most situations in which an intruding

or interfering noise may influence an acoustic environment (hearing damage due to high noise levels, interference with speech, interference with telephone use and safety or warning signals, and noise annoyance at work and at home).

(2) In a complex problem, there may be a multiplicity of criteria as well as a multiplicity of sources and paths. An ultimate design might have to incorporate simultaneously a hearing protection criterion for one operator, reliable speech or telephone communication for another operator, acceptable office noise levels for other personnel, and acceptable sleeping conditions for still other personnel.

c. Step 3, noise reduction requirements.

(1) The required noise reduction is that amount of noise level that exceeds the applicable criterion level. Only simple subtraction is involved, but, again, it is essential that all noise sources be considered at each of the various criterion situations.

(2) Some noise sources are predominantly of high-frequency content and add little low-frequency noise to the problem, while others are predominantly lowfrequency. Thus, frequency content by octave bands is important in determining the portion of excess noise contributed by a given source.

d. Step 4, noise control.

(1) Most common methods of controlling indoor noise by design considerations are set forth in the N&V manual: the effectiveness (transmission loss) of walls and structures in containing noise, and the effectiveness of distance and sound absorption (Room Constant) in reducing noise levels in the reverberant portion of a room. Special noise control treatments for use with engine installations are discussed in chapter 3 of this manual; they include mufflers, lined ducts, vibration isolation, the use of ear protection devices, and the use of nondistubing warning or paging systems.

(2) The influence of distance, outdoor barriers and trees, and the directivity of large sources are considered both as available noise control measures as well as factors in normal outdoor sound propagation (N&V manual).

2-3. Sound level criteria.

a. Indoor noise criteria. Noise criterion (NC) and preferred noise criterion (PNC) curves are used to express octave-band sound pressure levels considered acceptable for a wide range of occupied spaces. Paragraph 3-2 in the N&V manual discusses these noise criterion curves, which are directly applicable here for setting design goals for noise levels from engine installations. Tables 3-1 and 3-2 of the N&V manual summarize the octave-band sound pressure levels and the suggested applications of the NC and PNC curves. Also, in the N&V manual, paragraphs 3-2d and 3-3 relate to speech interference by noise, and paragraph 3-2e offers criteria for telephone usage in the presence of noise.

b. Community noise criteria. A widely used method for estimating the relative acceptability of a noise that intrudes into a neighborhood is described in paragraph 3-3c of the N&V manual. It is known as the Composite Noise Rating (CNR) method, modified over the years to include additional factors that are found to influence community attitudes toward noise. The method is readily applicable to the noise of engine installations (whether operating continuously or intermittently) as heard by community residents (whether on-base or off-base). Figures 3-3, 3-4, ad 3-5 and tables 3-4 and 3-5 of the N&V manual provide relatively simple access to the method. If the analysis shows that the noise will produce an uncomfortable or unacceptable community reaction to the noise, the method shows approximately how much noise reduction is required to achieve an acceptable community response to the noise.

c. Hearing conservation criteria. Paragraph 3-4 of the N&V manual reviews

briefly the history of key studies on the influence of high-level, long-time noise exposures on hearing damage, leading up the Occupational Safety and Health Act (OSHA) of 1970. The principal noise requirements of the act are summarized. A slightly more conservative and protective attitude toward hearing conservation
is contained in the DoD Instruction 6055.3. This document is summarized in paragraph 3-4d of the N&V manual. In brief, this document defines an exposure in excess of 84 dB(A) for 8 hours in any 24-hour period as hazardous and provides a formula for calculating the time limit of safe exposure to any A-weighted sound level (equation 3-4 and table 3-9 of the N&V manual). Other parts of DoD Instruction 6055.3 refer to impulsive noise, noise-hazardous areas, labeling of noise-hazardous tools and areas, issuance and use of hearing protection devices, educational programs on the effects of noise, audiometric testing programs, and the importance of engineering noise control for protecting personnel from noise.

d. Application of criteria to power plant noise. Each of the above three criteria evaluations should be applied to plants with engine installations, and the total design of each plant or engine installation should contain features or noise control treatments aimed at achieving acceptable noise levels for nearby offices and work spaces, for community housing facilities on and off the base, and for personnel involved with the operation and maintenance of the engines and plants.

2-4. Vibration criteria.

Reciprocating engines produce large, impulsive, unbalanced forces that can produce vibration in the floors on which they are mounted and in the buildings in which they are housed, if suitable vibration isolation mountings are not included in their designs. High-speed turbine-driven equipment must be well balanced by design to operate at speeds typically in the range of 3600 to 6000 rpm and, consequently, are much less of a potential vibration source in most installations, but they must have adequate isolation to reduce high-frequency vibration and noise. Chapter 4 of the N&V manual is devoted to noise from vibrating surfaces. Vibration control is less quantitative and predictable than noise control, but suggestions for vibration isolation of engine installations are given in paragraphs 3-6, 3-7, and 3-8 of this manual.

2-5. Indoor sound distribution.

Sound from an indoor sound source spreads around a room of normal geometry in a fairly predictable manner, depending on room dimensions, distance from the source, and the amount and effectiveness of sound absorption material in the room.

a. Sound transmission through walls, floors, and ceilings. Sound energy is also transmitted by the bounding walls and surfaces of the "source room" to adjoining spaces (the "receiving rooms"). The transmission loss of the walls and surfaces determines the amount of escaping sound to these adjoining rooms. Chapter 5 of the N&V manual gives details for calculating the indoor distribution of sound from the sound source (expressed either as PWL or SPL) into the room containing the source, and then to any adjoining room above, below, or beside the source room. Figures, table, equations and data forms in chapter 5 of the N&V manual provide the quantitative data and steps for evaluating indoor sound. The resulting sound level estimates are then compared with sound criteria selected for the spaces to determine if the design goals will be met or if more or less acoustic treatment is warranted. Power plant equipment is traditionally noisy, and massive walls, floors, and ceilings are required to confine the noise.

b. Doors, windows, openings. Doors, windows, and other openings must be considered so that they do not permit excessive escape of noise. Paragraph 5-4e of the N&V manual shows how to calculate the effect of doors and windows on the transmission loss of a wall.

c. Control rooms. Control rooms or personnel booths in the machinery rooms should be provided to ensure that work spaces and observation areas for personnel responsible for equipment operation are not noise-hazardous.

d. Buffer zones. Building designs should incorporate buffer zones between the noise equipment rooms and any nearby quiet work or rest areas (see table 3-2 of N&V manual for the category 1 to 3 areas that require very quiet acoustic background levels). Otherwise, massive and expensive construction is required to provide adequate noise isolation between adjoining noisy and quiet spaces.

2-6. Outdoor sound propagation.

An outdoor unenclosed diesel engine with a typical exhaust muffler but with no other silencing treatment can be heard at a distance of about 1 mile in a quiet rural or suburban area under good sound propagation conditions. At closer distances, it can be disturbing to neighbors. An inadequately muffled intake or discharge opening of a gas turbine engine can also result in disturbing sound levels to neighbors at large distances. When there are no interfering structures or large amounts of vegetation or woods that break the line of sight between a source and a receiver, normal outdoor sound propagation is fairly accurately predictable for long-time averages. Variations can occur with wind and large changes in thermal structures and with extremes in air temperatures and humidity. Even these variations are calculable, but the long-time average conditions are the ones that determine the typical sound levels received in a community, which in turn lead to judgments by the community on the relative acceptability or annoyance of that noise. Large solid structures or heavy growths of vegetation or woods that project well beyond the line of sight between the source and receiver area reduce the sound levels at the receiver positions. Chapter 6 of the N&V manual gives detailed information on all the significant factors that influence outdoor sound propagation, and it is possible to calculate quite reliably the expected outdoor sound levels at any distance from a source for a wide range of conditions that include distance, atmospheric effects, terrain and vegetation effects, and solid barriers (such as hills, earth berms, walls, buildings, etc.) Directivity of the source may also be a factor that influences sound radiation; for example, chapter 7 data in the N&V manual and paragraph 2-8c in this manual indicate special directivity

effects of large intake and exhaust stacks of gas turbine engines. The calculated or measured sound levels in a community location can then be analyzed by the CNR (composite noise rating) method of chapter 3 of the N&V manual to determine how the noise would be judged by the residents and to decide if special noise control treatment s should be
applied. Some examples of outdoor sound calculations are given in chapter 6 of the N&V manual.

2-7. Reciprocating engine noise data.

a. Data collection. Noise data have been collected and studied for more than
50 reciprocating diesel or natural-gas engines covering a power range of 160 to 7200 hp (115 to 5150 kW). The speed range covered was 225 to 2600 rpm; the larger engines run slower and the smaller engines run faster. Cylinder configurations include in-line V-type, and radial, and the number of cylinders ranged from 6 to 20. The engines were about equally divided between 2-cycle and 4-cycle operation; about 20% of the engines were fueled by natural gas, while the remainder were diesel; many of the smaller engines had naturally aspirated inlets but most of the engines had turbocharged inlets. The largest engines had cylinders with 15- to 21-in. bores and 20- to 31-in. strokes. Fourteen different

engine manufacturers are represented in the data. At the time of the noise measurements, about 55 percent of the engines were in the age bracket of 0 to 3 years, 32 percent were in the age bracket of 3 to 10 years, and 13 percent were over 10 years old.

b. Objective: noise prediction. The purpose of the study was to collect a large quantity of noise data on a broad range of engines and to set up a noise prediction scheme that could fairly reliably predict the noise level of any engine, on the basis of its design and operating conditions. This prediction method could then be applied to any engine in an installation, and its noise could be estimated and taken into account in setting up the design for the facility--all without anyone's actually having measured the particular engine. The prediction method performs very satisfactorily when tested against the 50 engines that were measured and used in the study. For three groups of engine casing noise data, the standard deviation between the measured noise and the predicted noise was in the range of 2.1 to 2.5 dB. This finding shows that the engines themselves are fairly stable sound sources and that the prediction method reflects the engine noise parameters quite well.

c. Engine noise sources. Typically, each engine has three principal sound sources: the engine casing, the engine exhaust, and the air inlet. The engine exhaust, when unmuffled, is the strongest source, since it represents an almost direct connection from the cylinder firings. The engine casing radiates noises and vibration caused by all the internal components of the operating engine, and is here assumed to include also the auxiliaries and appendages connected to the engine. For small engines, the air intake noise is taken as a part of the casing noise since it is relatively small and close to the engine and would be difficult to separate, acoustically, from engine noise. For larger engines, intake noise is easily separated from casing noise if the inlet air is ducted to the engine from some remote point. Most large engines are turbocharged; that is, the inlet air to the engine is pressurized to obtain higher performance. A typical turbocharger is a small turbine in the intake path that is driven by the high-the pressure exhaust from the engine. Special blowers are sometimes used to increase pressure and airflow into the engine. In d, e, and f below, sound power levels (PWLs) are given for the three basic sources of engine noise. The N&V manual (paras 2-5 and 5-3g) shows how to use PWL data.

d. Engine casing noise. The estimated overall PWL of the noise radiated by the casing of a natural-gas or diesel reciprocating engine is given in table 2-1. This PWL may be expressed by equation 2-1:

L+w+ = 93 + 10 log (rated hp) + A + B + C + D, (2

where L+w+ is the overall sound power level (in dB relative to 10+ -12+w), "rated hp" is the engine manufacturer's continuous full-load rating for the engine (in horsepower), and A, B, C, and D are correction terms (in dB), given in table 2-1. In table 2-1, "Base PWL" equals 93 + 10 log (rated hp).

Table 2-1. Estimated overall PWL for the casing of diesel and gas reciprocating engines.
Overall: L+w+ = Base PWL + A + B + C + D,
where "Base PWL" is related to "rated hp" of engine according to the upper portion of this table and the correction terms A, B, C, and D are identified and evaluated in the lower portion of this table. "Rated hp" is the engine manufacturer's continuous full-load rating for the engine in horsepower. If the engine is rated in kW, use hp = 1.4 kW.

Rated hp	Base PWL	Rated hp	Base PWL	Rated hp	Base PWL
9-11	103	90-112	113	892-1120	123
12-14	104	113-141	114	1130-1410	124
15-17	105	142-177	115	1420-1770	125
18-22	106	178-223	116	1780-2230	126
23-28	107	224-281	117	2240-2810	127
29-35	108	282-354	118	2820-3540	128
36-44	109	355-446	119	3550-4460	129
45-56	110	447-562	120	4470-5620	130
57-70	111	563-707	121	5630-7070	131
71-89	112	708-891	122	7080-8910	132

Correction Terms	in dB
Speed correction term "A"	
Under 600 rpm	-5
600-1500 rpm	-2
Above 1500 rpm	0
Fuel correction term "B"	
Diesel fuel only	0
Diesel and/or natural gas	0
Natural gas only (may have small amount of "pilot oil")	3
Cylinder arrangement term "C"	
In-line	0
V-type	-1
Radial	-1
Air intake correction term "D"	
Unducted air inlet to unmuffled Roots Blower	+3
Ducted air from outside the room or into muffled Roots Blower	0
All other inlets to engine (with or without turbochargers)	0

Octave-band PWLs can be obtained by subtracting the table 2-2 values from the overall PWL given by table 2-1 or equation 2-1. The octave-band corrections are different for the different engine speed groups.

Table 2-2. Frequency adjustments (in dB) for casing noise of reciprocating engines: Subtract these values from overall PWL (table 2-1 or eq. 2-1) to obtain octave-band and A-weighted PWLs.

Octave Frequency Band (Hz)	Value to be Subtracted From Overall PWL, in dB			
	Engine Speed Under 600 rpm	Engine Speed 600-1500 rpm: Without Roots Blower	Engine Speed 600-1500 rpm: With Roots Blower	Engine Speed Over 1500 rpm
31	12	14	22	22
63	12	9	16	14
125	6	7	18	7
250	5	8	14	7
500	7	7	3	8
1000	9	7	4	6
2000	12	9	10	7
4000	18	13	15	13
8000	28	19	26	20
A-weighted, dB(A)	4	3	1	2

For small engines (under about 450 hp), the air intake noise is not easy to separate, so the engine casing noise includes air intake noise (for both naturally aspirated and turbocharged engines).

e. Turbocharged air inlet. Most large engines have turbochargers to provide pressurized air into the engine inlet. The turbocharger is driven by the released exhaust gas of the engine. The turbine is a high-frequency sound source. Turbine configuration and noise output can vary appreciably, but an approximation of the overall PWL of the turbocharger noise is given by table 2-3 or equation 2-2:

$$L_w = 94 + 5 \log (\text{rated hp}) - L_{in}/6, \qquad (2\text{-}2)$$

where L_w and "rated hp" are already defined and L_{in} is the length, in feet, of a ducted inlet to the turbocharger. For many large engines, the air inlet may be ducted to the engine from a fresh air supply or a location outside the room or building. The term $L_{in}/6$, in dB, suggests that each 6 ft. of inlet ductwork, whether or not lined with sound absorption material, will provide about 1 dB of reduction of the turbocharger noise radiated from the open end of the duct. This is not an accurate figure for ductwork; it merely represents a simple token value for this estimate. The reader should refer to the ASHRAE Guide (See app. B) for a more precise estimate of the attenuation provided by lined or unlined ductwork. In table 2-3, "Base PWL" equals 94 + 5 log (rated hp). The octave-band values given in the lower part of table 2-3 are subtracted from the overall PWL to obtain the octave-band PWLs of turbocharged inlet noise.

Table 2-3. Estimated PWL for turbocharger noise at air inlet opening of turbocharged reciprocating engines.

Overall: $L_w = \text{Base PWL} - L_{in}/6$,

where "Base PWL" is related to "rated hp" of engine according to the upper portion of this table. L_{in} is the length, in feet, of added inlet duct (if any) from air cleaner to the turbocharger. Lower portion of table gives frequency adjustments; subtract these values from overall PWL to obtain octave band and A-weighted PWLs.

Rated hp	Base PWL	Rated hp	Base PWL	Rated hp	Base PWL
8-12	99	80-125	104	795-1250	109
13-19	100	126-199	105	1260-1990	110
20-31	101	200-316	106	2000-3160	111
32-50	102	317-501	107	3170-5010	112
51-79	103	502-794	108	5020-7940	113

Frequency Adjustments:

Octave Frequency Band (Hz)	Value to be Subtracted From Overall PWL (dB)
31	4
63	11
125	13
250	13
500	12
1000	9
2000	8
4000	9
8000	17
A-weighted, dB(A)	3

f. Engine exhaust. The overall PWL of the noise radiated from the unmuffled exhaust of an engine is given by table 2-4 or equation 2-3:

$$L_w = 119 + 10 \log (\text{rated hp}) - T - L_{ex}/4, \qquad (2\text{-}3)$$

where T is the turbocharger correction term and L_{ex} is the length, in feet, of the exhaust pipe. A turbocharger takes energy out of the discharge gases and results in approximately 6-dB reduction in noise. Thus, T = O dB for an engine without a turbocharger, and T = 6 dB for an engine with a turbocharger. In table 2-4, "Base PWL" equals 119 + 10 log (rated hp). The octave-band PWLs of unmuffled exhaust noise are obtained by subtracting the values in the lower part of table 2-4 from the overall PWL.

Table 2-4. Estimated PWL for unmuffled exhaust noise of diesel and gas reciprocating engines.

Overall: L+w+ = Base PWL - T - L+ex+/4,

where "Base PWL" is related to "rated hp" of engine according to the upper portion of this table. T is O for an engine without a turbocharger and
-6 dB for an engine with a turbocharger. L+ex+ is the length, in feet, of the exhaust pipe. Lower portion of table gives frequency adjustments; subtract these values from overall PWL to obtain octave band and A-weighted PWLs.

Rated hp	Base PWL	Rated hp	Base PWL	Rated hp	Base PWL
9-11	129	90-112	139	892-1120	149
12-14	130	113-141	140	1130-1410	150
15-17	131	142-177	141	1420-1770	151
18-22	132	178-223	142	1780-2230	152
23-28	133	224-281	143	2240-2810	153
29-35	134	282-354	144	2820-3540	154
36-44	135	355-446	145	3550-4460	155
45-56	136	447-562	146	4470-5620	156
57-70	137	563-707	147	5630-7070	157
71-89	138	708-891	148	7080-8910	158

Frequency Adjustments:

Octave Frequency Band (Hz)	Value to be Subtracted From Overall PWL (dB)
31	5
63	9
125	3
250	7
500	15
1000	19
2000	25

4000	35
8000	43
A-weighted, dB(A)	12

If the engine is equipped with an exhaust muffler, the final noise radiated from the end of the tailpipe is the PWL of the unmuffled exhaust minus the insertion loss, in octave bands, of the reactive muffler (para 3-3).

2-8. Gas turbine engine noise data.

a. Data collection. Noise data have been collected and studied for more than 50 gas turbine engines covering a power range of 180 kW to 34 MW, with engine speeds ranging from 3600 rpm to over 15,000 rpm. Some of the engines were stationary commercial versions of aircraft engines, while some were large massive units that have no aircraft counterparts. Most of the engines were used to drive electrical generators either by direct shaft coupling or through a gear. Eight different engine manufacturers are represented in the data. Engine configurations vary enough that the prediction is not as close as for the reciprocating engines. After deductions were made for engine housings or wrap-

pings and inlet and discharge mufflers, the standard deviation between the predicted levels and the measured levels for engine noise sources (normalized to unmuffled or uncovered conditions) ranged between 5.0 and 5.6 dB for the engine
casing, the inlet, and the discharge. In the data that follow, 2 dB have been added to give design protection to engines that are up to 2 dB noisier than the average.

b. Engine source data. As with reciprocating engines, the three principal noise sources of turbine engines are the engine casing, the air inlet, and the exhaust. The overall PWLs of these three sources, with no noise reduction treatments, are given in the following equations:

for engine casing noise,

L+w+ = 120 + 5 log (rated MW); (2-4)

for air inlet noise,

L+w+ = 127 + 15 log (rated MW); (2-5)

for exhaust noise,

L+w+ = 133 + 10 log (rated MW), (2-6)

where "rated MW" is the maximum continuous full-load rating of the engine in megawatts. If the manufacturer lists the rating in "effective shaft horsepower" (eshp), the MW rating may be approximated by

MW = eshp/1400.

Overall PWLs, obtained from equations 2-4 through 2-6, are tabulated in table 2-5 for a useful range of MW ratings.

Table 2-5. Overall PWLs of the principal noise components of gas turbine engines that have no noise control treatments.

Rated MW	Casing PWL dB	Inlet PWL dB	Exhaust PWL dB
0.10	115	112	123
0.13	116	114	124
0.16	116	115	125
0.20	117	117	126
0.25	117	118	127
0.32	118	120	128
0.40	118	121	129
0.50	118	122	130
0.63	119	124	131
0.80	120	126	132
1.0	120	127	133
1.3	121	129	134
1.6	121	130	135

2.0	122	132	136
2.5	122	133	137
3.2	123	135	138
4.0	123	136	139
5.0	123	137	140
6.3	124	139	141
8.0	125	141	142
10	125	142	143
13	126	144	144
16	126	145	145
20	127	147	146
25	127	148	147
32	128	150	148
40	128	151	149
50	128	152	150
63	129	154	151
80	130	156	152

Octave-band and A-weighted corrections for these overall PWLs are given in table 2-6.

Table 2-6. Frequency adjustments (in dB) for gas turbine engine noise sources: Subtract these values from overall PWLs (table 2-5) to obtain octave-band and Aweighted PWLs.

Octave Band Frequency (Hz)	Value To Be Subtracted From Overall PWL, in dB		
	Casing	Inlet	Exhaust
31	10	19	12
63	7	18	8
125	5	17	6
250	4	17	6
500	4	14	7
1000	4	8	9
2000	4	3	11
4000	4	3	15
8000	4	6	21
A-weighted, dB(A)	2	0	4

(1) Tonal components. For casing and inlet noise, particularly strong highfrequency sounds may occur at several of the upper octave bands, but specifically which bands are not predictable. Therefore, the octave-band adjustments of table 2-6 allow for these peaks in several different bands, even though they probably will not occur in all bands. Because of this randomness of peak frequencies, the A-weighted levels may also vary from the values quoted.

(2) Engine covers. The engine manufacturer sometimes provides the engine casing with a protective thermal wrapping or an enclosing cabinet, either of which can give some noise reduction. Table 2-7 suggests the approximate noise reduction for casing noise that can be assigned to different types of engine enclosures. The notes of the table give a broad description of the enclosures.

Table 2-7. Approximate noise reduction of gas turbine engine casing enclosures; see notes for enclosure types.

Octave Frequency Band (Hz)	Noise Reduction, dB Type 1	Type 2	Type 3	Type 4	Type 5
31	2	4	1	3	6
63	2	5	1	4	7
125	2	5	1	4	8
250	3	6	2	5	9
500	3	6	2	6	10
1000	3	7	2	7	11
2000	4	8	2	8	12
4000	5	9	3	8	13
8000	6	10	3	8	14

Note:

Type 1. Glass fiber or mineral wool thermal insulation with lightweight foil cover over the insulation.

Type 2. Glass fiber or mineral wool thermal insulation with minimum 20 gage aluminum or 24 gage steel or 1/2-in. thick plaster cover over the insulation.

Type 3. Enclosing metal cabinet for the entire packaged assembly, with open ventilation holes and with no acoustic absorption lining inside the cabinet.

Type 4. Enclosing metal cabinet for the entire packaged assembly, with open ventilation holes and with acoustic absorption lining inside the cabinet.

Type 5. Enclosing metal cabinet for the entire packaged assembly, with all ventilation holes into the cabinet muffled and with acoustic absorption lining inside the cabinet.

The values of table 2-7 may be subtracted from the octave-band PWLs of casing noise to obtain the adjusted PWLs of the covered or enclosed casing. An enclosure specifically designed to control casing noise can give larger noise reduction values than those in the table.

c. Exhaust and intake stack directivity. Frequently, the exhaust of a gas turbine engine is directed upward. The directivity of the stack provides a degree of noise control in the horizontal direction. Or, in some installations, it may be beneficial to point the intake or exhaust opening horizontally in a direction away from a sensitive receiver area. In either event, the directivity is a factor in noise radiation. Table 2-8 gives the approximate directivity effect of a large exhaust opening. This effect can be used for either a horizontal or vertical stack exhausting hot gases.

Table 2-8. Approximate directivity effect (in dB) of a large exhaust stack compared to a nondirectional source of the same power. See note for application to intake stack.

Octave Frequency Band (Hz)	Relative Sound Level for Indicated Angle From Axis				
	0 deg.	45 deg.	60 deg.	90 deg.[a]	135 deg, and larger [a]
31	8	5	2	-2	-3
63	8	5	2	-3	-4
125	8	5	2	-4	-6
250	8	6	2	-6	-8
500	9	6	2	-8	-10
1000	9	6	1	-10	-13
2000	10	7	0	-12	-16
4000	10	7	-1	-14	-18
8000	10	7	-2	-16	-20

[a] For air intake openings subtract 3 dB from the values in the 90 deg. and 135 deg. columns, i.e., -2 -3 = -5 dB for 31 cps at 90 deg.

[retrieve: Exhaust Stack.]

Table 2-8 shows that from approximately 0 deg.to 60 deg. from its axis, the stack will yield higher sound levels than if there were no stack and the sound were emitted by a nondirectional point source. From about 60 deg. to 135 deg. from the axis, there is less sound level than if there were no stack. In other words, directly ahead of the opening, there is an increase in noise, and off to the side of the opening, there is a decrease in noise. The table 2-8 values also apply for a large-area intake opening into a gas turbine for the 0 deg. to 60 deg. range; for the 90 deg. to 135 deg. range, subtract an additional 3 dB from the already negative-valued quantities. For horizontal stacks, sound-reflecting obstacles out in front of the stack opening can alter the directivity pattern. Even irregularities on the ground surface can cause some backscattering of sound into the 90 deg. to 180 deg. regions for horizontal stacks serving either as intake or exhaust openings.

d. Intake and exhaust mufflers. Dissipative mufflers for gas turbine inlet and discharge openings are considered in paragraph 3-4. The PWL of the noise radiated by a muffled intake or discharge is the PWL of the untreated source (from tables

2-5 and 2-6) minus the insertion loss of the muffler used, in octave bands.

2-9. Data forms.

Several data forms are developed and illustrated in the N&V manual. These forms aid in the collection, organization, and documentation of several calculation steps that are required in a complex analysis of a noise problem. Instructions for the use of those data forms (DD Forms 2294 through 2303) are given in the N&V manual, and blank copies of those data forms are included in appendix E of that manual. Many of the forms are used in the chapter 4 examples. In addition, two new DD forms are prescribed in this manual.

a. DD Form 2304. DD Form 2304 (Estimated Sound Power Level of Diesel or Gas Reciprocating Engine Noise) summarizes the data procedures required to estimate the PWL of a reciprocating engine (app A). Data for the various steps are obtained from paragraph 2-7 above or from an engine manufacturer, when such data are available. Parts A, B, and C provide the PWLs of the engine casing noise, the turbocharged air inlet noise (if applicable, and with or without sound absorption material in the inlet ducting), and the engine exhaust noise, with and without an exhaust muffler.

b. DD Form 2305. DD Form 2305 (Estimated Sound Power Level of Gas Turbine Engine Noise) summarizes the data and procedures for estimating the unquieted and quieted engine casing noise, air inlet noise, and engine exhaust noise (app A). Additional engine data and discussion are given in paragraph 2-8 above, and the insertion losses of a few sample muffler and duct configurations are given in paragraphs 3-4 and 3-5.

c. Sample calculations. Sample calculations using these two new data forms (DD Form 2304 and DD Form 2305) appear in chapter 4.

2-10. Other noise sources.

Gears, generators, fans, motors, pumps, cooling towers and transformers are other pieces of equipment often used in engine-driven power plants. Refer to chapter 7 of the N&V manual for noise data on these sources.

CHAPTER 3
NOISE AND VIBRATION CONTROL
FOR ENGINE INSTALLATIONS

3-1. Engine noise control.

There are essentially three types of noise problems that involve engines and power plant operations: Engine noise has the potential of causing hearing damage to people who operate and maintain the engines and other related equipment; engine noise is disturbing to other personnel in the same building with the engine (or in a nearby building); and power plant noise is disturbing to residential neighbors living near the plant. Noise control is directed toward meeting and solving these three types of problems. In addition to the noise control procedures contained in the N&V manual, this manual provides material on mufflers, duct lining, vibration isolation of engines, the use of hearing protection devices (ear plugs and ear muffs), and a special application of room acoustics in which the indoor noise escapes outdoors through a solid wall or an opening in the wall. Each of the three types of noise problems requires some of these treatments.

a. Noise control for equipment operators. Equipment operators should be kept out of the engine room most of the time, except when they are required to be in the room for equipment inspection, maintenance, repair, or replacement. When personnel are in the room, and while the equipment is running, ear protection should be worn, because the sound levels are almost certain to be above the DoD 84-dB(A) sound level limit. Various forms of engine covers or enclosures for turbine engines are usually available from the manufacturers. Data on the noise reduction provided by these marketed covers can be approximated from table 2-7. A separate control room beside the engine room or a suitable personnel booth located inside the engine room can be used by the operator to maintain visual contact with the engine room and have ready access to it, yet work in a relatively quiet environment. The telephone for the area should be located inside the control room or personnel booth. An example of a control room calculation is included in paragraph 8-3b of the N&V manual and in paragraph 4-2 of this manual.

b. Noise control for other personnel in the same (or nearby) building with the engine. Noise control for this situation is obtained largely by architectural design of the building and mechanical design of the vibration isolation mounting system. The architectural decisions involve proper selection of walls, floors, ceilings, and buffer zones to control noise escape from the engine room to the adjoining or other nearby rooms (refer to N&V manual). A reciprocating engine should be fitted with a good exhaust muffler (preferably inside the engine room), and if the discharge of the exhaust pipe at its outdoor location is too loud for building occupants or nearby neighbors, a second large-volume, low-pressure-drop muffler should be installed at the end of the exhaust pipe. The approval of the engine manufacturer should be obtained before installation and use of any special muffler or muffler configuration, because excessive back-pressure can be harmful to the engine (para 3-3 discusses reactive mufflers). A turbine engine will require both an inlet and a discharge muffler (para 3-4 discusses dissipative mufflers), and an engine cover (table 2-7) will be helpful in reducing engine room noise levels. An air supply to the room must be provided (for room ventilation and primary air for engine combustion) for both reciprocating and turbine engines, and the muffled, ducted exhaust from turbine engines must be discharged from the building. Vibration isolation is essential for both types of engines, but reciprocating engines represent the more serious vibration problem. Large reciprocating engines must not be located on upper floors above critical locations without having very special sound and vibration control treatments. All reciprocating engines should be located on grade slabs as far as possible from critical areas of the building (categories 1 to 3 in table 3-2 of the N&V manual). Vibration isolation recommendations are given in paragraphs 3-6, 3-7, and 3-8.

c. Control of noise to neighbors by outdoor sound paths. If an engine installation is already located outdoors and its noise to the neighbors is not more than about 10 to 15 dB above an acceptable level, a barrier wall can possibly provide the necessary noise reduction (para 6-5 of the N&V manual). If the existing noise excess is greater than about 15 dB or if a new installation is being considered, an enclosed engine room should be used. The side walls and roof of the room (including doors and windows) should have adequate TL (transmission loss; para 5-4 of the N&V manual), ventilation openings for the room and engine should be acoustically treated to prevent excessive noise escape, and, finally, the total of all escaping noise should be estimated and checked against the CNR rating system for neighborhood acceptance (para 3-3c of the N&V manual).

3-2. Noise escape through an outdoor wall.

A lightweight prefabricated garage-like structure might be considered as a simple enclosure for a small on-base power plant. The transmission loss of such a structure might be inadequate, however, and the enclosure would not serve its intended purpose. A calculation procedure is given here for evaluating this situation.

a. Noise radiated outdoors by a solid wall. With the use of the "room acoustics" material in paragraph 5-3 of the N&V manual and the source data in paragraphs 2-7 and 2-8 of this manual and in chapter 7 of the N&V manual, it is possible to calculate the reverberant sound pressure level L+p+in++ inside an engine room along the wall that radiates noise to the outdoors. The sound pressure level L+p+out++ just outside that wall is obtained by modifying equation 5-4 in the N&V manual. The N&V equation 5-4 is repeated here:

L+p+2++= L+p+1++ - TL + 10 log (1/4 + S+w+/R+2+).

This equation is modified to become equation 3-1 below for the case of the sound pressure level outside the wall. In this modified form, R+2+ (the Room Constant of the "receiving room") becomes infinite. Then S+w+/R+2+ becomes zero, and the remaining quantity 10 log 1/4 is -6 dB. Thus, equation 3-1 is:

L+p+out++ = L+p+in++ - TL 6 dB. (3-1)

The sound power level L+w+ radiated by this wall is (from eq. 7-18 in the N&V manual)

L+w+ = L+p+out++ + 10 log A - 10, (3-2)

where A is the area of the radiating wall, in ft.+2+ Equation 3-3 combines equations 3-1 and 3-2:

L+w+ = L+p+in++ TL + 10 log A - 16. (3-3)

This equation must be used carefully. For a large area wall with a low TL in the low-frequency region, it is possible for equation 3-3 to yield a calculated value of sound power level radiated by the wall that exceeds the sound power level of the source inside the room. This would be unrealistic and incorrect. Therefore, when equation 3-3 is used, it is necessary to know or to estimate the PWL of the indoor sound source (or sources) and not allow the L+w+ of equation 3-3 to exceed that value in any octave band. When the PWL of the radiating wall is known, the SPL at any distance of interest can be calculated from equation 6-1 or tables 6-3 or 6-4 of the N&V manual. The directivity of the sound radiated from the wall is also a factor. If the engine room is free to radiate sound from all four of its walls, and if all four walls are of similar construction, the area A in equation 3-3 should be the total area of all four walls, and the radiated sound is assumed to be transmitted uniformly in all directions. If only one wall is radiating the sound toward the general direction of the neighbor position, it may be assumed that the sound is transmitted uniformly over a horizontal angle that is 120 deg. wide, centered at a line that is perpendicular to the wall under consideration. This procedure will give a calculated estimate of the SPL at a neighbor position fr sound transmitted through a solid wall whose TL and area are known. Of course, if a lightweight wall does not have sufficient TL to meet the need, a heavier wall should be selected.

b. Noise radiated by a wall containing a door or window. The procedure followed in a above for a solid wall is readily adaptable to a wall containing a door or window or other surface or opening having a TL different from that of the wall. It is necessary to calculate the effective TL+c+ of the composite wall and to use TL+c+ in the procedure above. The TL+c+ of the composite wall may be determined from one of the methods given in paragraph 5-4e of the N&V manual.

c. Noise radiated from an opening in a wall. An opening in an outside wall may be required to permit ventilation of the room or to supply air to an engine. Noise escaping through that opening might be disturbing to the neighbors. The sound power level L+w+ of the escaping noise can be calculated with the material given in paragraph 7-22 in the N&V manual, and the SPL at the neighbor position estimated from the tables 6-3 or 6-4 distance terms of the N&V manual. If excessive amounts of noise escape through the opening, a dissipative muffler should be installed in the opening (para 3-4).

d. Noise radiated from the roof of a building. Noise from inside a building will escape through the roof of that building. For a building with a practically flat roof and a 2- to 5-ft.-high parapet around the edge of thereof, the noise radiated from the roof has a significant upward directivity effect. This results in a lower amount of sound radiated horizontally from the roof surface. There are no measured field data for the directivity effect of roof-radiated sound, but a reasonable estimate of this effect is given in table 3-1. Without a parapet around the roof, slightly larger amounts of sound are radiated horizontally; and a sloping room radiates still higher amounts of sound horizontally.

Table 3-1. Reduction of roof-radiated sound in the horizontal direction for various roof types and dimensions.

Octave Frequency Band (Hz)	Type 1 Roof D over 50 ft.	Type 1 Roof D under 50 ft.	Type 2 Roof D over 50 ft.	Type 2 Roof D under 50 ft.	Type 3 Roof D over 50 ft.	Type 3 Roof D under 50 ft.
31					6	3
63	8	5	7	4	6	3
125	10	7	8	5	7	4
250	12	10	10	8	8	6
500	14	12	11	9	9	7
1000	16	15	13	12	10	8
2000	18	18	14	14	11	9
4000	20	20	16	16	12	10
8000	22	22	18	18	14	12

[retrieve: Roof Types]

Since the directivity is also related to wavelength of sound, large values of roof dimension D have higher vertical directivity and therefore a greater reduction of horizontally radiated sound than do smaller values of D. All these variations are represented in table 3-1. The total PWL of the sound radiated from a roof is estimated with the use of equation 3-3. where TL is the transmission loss of the roof structure and A is the area of the exposed roof. The horizontally radiated sound power is then the total PWL minus the table 3-1 values.

3-3. Reactive mufflers for reciprocating engines.

Reactive mufflers are used almost entirely for gas and diesel reciprocating engine exhausts. Reactive mufflers usually consist of 2 or 3 large-volume chambers containing an internal labyrinth-like arrangement of baffles, compartments, and perforated tubes and plates. Reactive mufflers smooth out the flow of impulsive-exhaust discharge and, by the arrangement of the internal components, attempt to reflect sound energy back toward the source. There is usually no acoustic absorption material inside a reactive muffler. Most manufacturers of these exhaust mufflers produce three grades or sizes, based on the amount of noise reduction provided. Generally, for a particular engine, the larger the muffler, the greater the insertion loss or noise reduction. Table 3-2 gives the approximate insertion loss of the three classes of mufflers. The PWL of the noise radiated by a muffled engine exhaust is the PWL of the unmuffled exhaust minus the insertion loss of the muffler.

Table 3-2. Approximate insertion loss (in dB) of typical reactive mufflers used with reciprocating engines.

Octave Frequency Band (Hz)	Low Pressure-Drop Muffler Series by Relative Size			High Pressure-Drop Muffler Series by Relative Size		
	Small	Medium	Large	Small	Medium	Large
63[a]	10	15	20	16	20	25
125	15	20	25	21	25	29
250	13	18	23	21	24	29
500	11	16	21	19	22	27
1000	10	15	20	17	20	25
2000	9	14	19	15	19	24
4000	8	13	18	14	18	23
8000	8	13	18	14	17	23

Refer to manufacturers' literature for more specific data.

[a] Insertion loss values usually are not measured and quoted for the 31-Hz octave band. For calculations, assume the 31-Hz insertion loss is about 60% of the 63-Hz insertion loss, rounded off to the nearest decibel.

a. Muffler grades and sizes. Typically, the three different grades of mufflers are labeled with names that indicate the relative degree of criticalness of the noise problem involved, such as "commercial," "residential" and "suburban," or "standard." "semicritical" and "critical," or similar series of names and models. Very approximately, the overall volume of the middle-size or second muffler in the series is about 1.4 to 1.6 times the volume of the smallest or first muffler in the series, while the volume of the largest or third muffler in the series is about 2 to 2.5 times the volume of the first muffler. An engine manufacturer will usually recommend a maximum length and minimum exhaust pipe for an engine, as these influence the back-pressure applied to the engine exhaust. Low-pressure-drop mufflers are normally required for turbocharged engines because the turbocharger has already introduced some pressure drop in the exhaust line.

b. Caution. The insertion loss values of table 3-2 are offered only as estimates because other factors in the installation may affect the noise output of the engine--such factors as the exhaust pipe dimensions and layout, backpressure in the system, and location of the muffler. The engine manufacturer's approval or suggestions should be obtained for unusual muffler arrangements.

3-4. Dissipative mufflers.

A gas turbine engine typically requires a muffler at the air intake to the engine and another muffler at the engine exhaust. Depending on the arrangement, either a reciprocating or a turbine engine may also require some muffling for ventilating air openings into the engine room, and some of the packaged gas turbine units may require some muffling for auxiliary fans, heat exchangers or for ventilation openings into the generator and/or gear compartment. The mufflers required for these situations are knows as "dissipative" mufflers. As the name implies, dissipative mufflers are made up of various arrangements of sound absorbent material, which actually absorbs sound energy out of the moving air or exhaust stream. The most popular configuration is an array of "parallel baffles" placed in the air stream. The baffles may range from 2-in. to 16-in. thick, and are filled with glass fiber or mineral wool. Under severe uses, the muffler material must be able to withstand the operating temperature of the air or gas flow, and it must have adequate internal construction and surface protection to resist the destruction and erosion of high-speed, turbulent flow. These mufflers should be obtained from an experienced, reputable manufacturer to insure proper quality of materials, design, workmanship, and ultimately, long life and durability of the unit. Dissipative mufflers are divided here into two groups: The special customer-designed and constructed mufflers for gas turbine engines and other heavy-duty applications, and ventilation-dict mufflers that are stock items manufactured and available from several companies.

a. Gas turbine mufflers. Noise from the air inlet of a gas turbine is usually strong in the high-frequency region and is caused by the blade passage frequencies of the first one or two compressor stages of the turbine. Thin parallel baffles of approximately 4-in. thickness, with 4-in. to 6-in. air spaces between baffles, are quite effective in reducing high-frequency sound. The discharge noise of a gas turbine engine, on the other hand, is strong in the lowfrequency region. Mufflers must have large dimensions to be effective in the low-frequency region, where wavelength dimensions are large (para 2-6b of the N&V manual). Thus, these baffles may be 6-in. to 18-in. thick, with 8-in. to 16-in air spaces between baffles, and have rugged construction to withstand the high temperature and turbulent flow of the engine discharge. Depending on the seriousness of the noise problems, mufflers may range from 8 ft. to 20 ft. in length, and for very critical problems (i.e., very close neighbors), two different 12- to 18-ft. mufflers (different baffle dimensions) may be stacked in series to provide maximum insertion loss over a broad frequency range.

(1) When large amounts of loss are required, baffles are installed at close spacings with perhaps only 30 to 50 percent open air passage through the total muffler cross section. This, in turn, produces a high pressure drop in the flow, so the final muffler design represents a compromise of cost, area, length, pressure drop, and frequency response. Pressure drop of flow through the muffler can usually be reduced by fitting a rounded or pointed end cap to the entrance and exits ends of a baffle.

(2) The side walls of the chamber that contains the muffler must not permit sound escape greater than that which passes through the muffler itself. Thus, the side walls at the noisy end of the muffler should have a TL at least 10 dB greater than the insertion loss of the muffler for each frequency band. At the quiet end of the muffler, the TL of the size walls can be reduced to about 10 dB greater than one-half the total insertion loss of the muffler.

(3) In the contract specifications, the amount of insertion loss that is expected of a muffler should be stated so that the muffler manufacturer may be held to an agreed-upon value. It is more important to specify the insertion loss than the dimension and composition of the muffler because different manufacturers may have different, but equally acceptable, fabrication methods for achieving the values.

(4) Operating temperatures should also be stated. When dissipative mufflers carry air or gas at elevated temperatures, the wavelength of sound is longer, so the mufflers appear shorter in length (compared to the wavelength) and therefore less effective acoustically (para 2-6b of the N&V manual.)

(5) As an aid in judging or evaluating muffler performance, tables 3-3 through 3-8 give the approximate insertion loss values to be expected of a number of muffler arrangements. Values may vary from one manufacturer to another, depending on materials and designs.

Table 3-3. Approximate insertion loss (in dB) of 8-ft.-long, 4-in.-thick parallel baffles separated by various with air spaces.

Octave Frequency Band (Hz)	Width of Air Space: 4 In.	8 In.	12 In.	16 In.	24 In.
	Percent Open Area: 50%	67%	75%	80%	86%
63[a]	3	2	1	1	0
125	6	5	3	2	2
250	16	13	8	6	4
500	32	25	16	13	10
1000	56	38	19	16	12
2000	48	35	13	11	8
4000	40	26	10	8	6
8000	20	18	7	6	4

[a] Insertion loss values usually are not measured and quoted for the 31-Hz octave band. For calculations, assume the 31-Hz insertion loss is about 60% of the 63-Hz insertion loss, rounded off to the nearest decibel.

Table 3-4. Approximate insertion loss (in dB) of various lenghts 4-in.-thick parallel baffels separated by 8-in.-wide air spaces (67% open air).

Octave Frequency Band (Hz)	Length of Baffles: 4 Ft.	8 Ft.	12 Ft.	16 Ft.
63[a]	1	2	3	4
125	3	5	7	9
250	8	13	18	22
500	16	25	34	43
1000	25	38	52	65
2000	22	35	47	58
4000	17	26	34	41
8000	13	18	23	27

[a] Insertion loss values usually are not measured and quoted for the 31-Hz octave band. For calculations, assume the 31-Hz insertion loss is about 60% of the 63-Hz insertion loss, rounded off to the nearest decibel.

Table 3-5. Approximate insertion loss (in dB) of various lengths of 8-in.-thick parallel baffles separated by 12-in.-wide air spaces (60% open area).

Octave Frequency Band (Hz)	Length of Baffles			
	4 Ft.	8 Ft.	12 Ft.	16 Ft.
63[a]	2	4	5	7
125	5	8	11	14
250	10	18	25	32
500	16	27	37	46
1000	15	23	31	38
2000	13	19	25	30
4000	10	14	19	24
8000	6	10	14	17

[a] Insertion loss values usually are not measured and quoted for the 31-Hz octave band. For calculations, assume the 31-Hz insertion loss is about 60% of the 63-Hz insertion loss, rounded off to the nearest decibel.

Table 3-6. Approximate insertion loss (in dB) of various lengths of 8-in.-thick parallel baffles separated by 8-in.-wide air spaces (50% pen area).

Octave Frequency Band (Hz)	Length of Baffles			
	4 Ft.	8 Ft.	12 Ft.	16 Ft.
63[a]	3	5	7	9
125	6	11	16	20
250	12	20	28	36
500	18	30	42	53
1000	17	27	36	44
2000	15	22	29	35
4000	13	18	23	27
8000	11	15	18	21

[a] Insertion loss values usually are not measured and quoted for the 31-Hz octave band. For calculations, assume the 31-Hz insertion loss is about 60% of the 63-Hz insertion loss, rounded off to the nearest decibel.

Table 3-7. Approximate insertion loss (in dB) of various lengths of 12-in.-thick parallel baffles separated by 12-in.-wide air spaces (50% open area).

Octave Frequency Band (Hz)	Length of Baffles			
	4 Ft.	8 Ft.	12 Ft.	16 Ft.
63[a]	3	5	8	12
125	7	12	18	23
250	12	20	28	35
500	18	30	41	51
1000	15	24	33	41
2000	13	19	21	32
4000	10	14	19	24
8000	6	10	14	17

[a] Insertion loss values usually are not measured and quoted for the 31-Hz octave band. For calculations, assume the 31-Hz insertion loss is about 60% of the 63-Hz insertion loss, rounded off to the nearest decibel.

Table 3-8. Approximate insertion loss (in dB) of various lengths of 16-in.-thick parallel baffles separated by 10-in.-wide air spaces (38% open area).

Octave Frequency Band (Hz)	Length of Baffles			
	4 Ft.	8 Ft.	12 Ft.	16 Ft.
63[a]	5	11	15	18
125	10	16	22	27
250	16	23	30	36
500	19	32	42	50
1000	16	25	34	42
2000	14	22	29	34
4000	12	17	22	27
8000	10	14	18	21

[a] Insertion loss values usually are not measured and quoted for the 31-Hz octave band. For calculations, assume the 31-Hz insertion loss is about 60% of the 63-Hz insertion loss, rounded off to the nearest decibel.

b. "Lined" and "unlined" bends in turbine stacks. When a long duct or passageway contains a square-ended 90 deg. turn, there is a tendency for sound traveling in that duct to be reflected back toward the direction from which it came. Because high-frequency sound is more "directional" (behaves more nearly as a beam of light), it is more readily reflected back by the end wall of the 90 deg. turn and less sound is transmitted around the corner. Low-frequency sound "bends" around the turn more readily, so this reflection effect is less pronounced. The attenuation provided by a square-ended 90 deg. turn can be increased noticeably by adding a thick lining of acoustic absorption material at the end of the turn (facing the oncoming sound wave), extending into the duct past the turn for a length of one or two times the average width of the duct. A long muffler, located immediately past the turn, also serves to simulate a lined bend. Table 3-9 gives the estimated insertion loss of unlined and lined bends, and figure 3-1 shows schematically the bend configurations. The orientation of the parallel baffles of a muffler located just past a turn should be as shown in figure 3-1 to achieve the Class 1 and Class 2 lined bend effects.

Table 3-9. Approximate insertion loss (in dB) of unlined and lined square-ended 90 deg. turn. Figure 3-1 shows types and dimensions of turn configurations.

Octave Frequency Band (Hz)	Unlined Bend	Lined Bend Class 1	Lined Bend Class 2
63[a]	2	3	5
125	3	5	7
250	4	6	8
500	5	8	10
1000	6	9	12
2000	7	11	14
4000	8	12	16
8000	9	14	18

[a] Insertion loss values usually are not measured and quoted for the 31-Hz octave band. For calculations, assume the 31-Hz insertion loss is about 60% of the 63-Hz insertion loss, rounded off to the nearest decibel.

[retrieve: Figure 3-1. Schematic arrangement of "unlined" and "lined" bends in ducts or passages (see text or discussion).]

Turning vanes in the 90 deg. square turn reduce the insertion loss values. If turning vanes are used, only one-half the insertion loss values of table 3-9 may be used for the 63- through 500-Hz bands and only one-fourth the values for the 1000- through 8000-Hz bands. When a muffler is used at the turn, full attenuation of the muffler is realized as well as the additional loss due to the lined turn.

c. Ventilation-duct muffles. For ducted air-handling, ventilation, or air-conditioning systems, packaged duct mufflers can be purchased directly from reputable acoustical products suppliers. Their catalogs show the available dimensions and insertion losses provided in their standard rectangular and circular cross-section mufflers. These packaged duct mufflers are sold by manufacturers in 3-ft., 5-ft., and 7-ft. lengths. They are also usually available in two or three "classes," depending on attenuation. The mufflers of the higher insertion loss class typically have only about 25% to 35% open area, with the remainder of the space filled with absorption material. The lower insertion-loss classes have about 50% open area. The mufflers with the larger open area have less pressure drop and are known as "low-pressure-drop units." The mufflers with the smaller open area are known as "high-pressure-drop units." When ordering special purpose mufflers, one should state the speed and the temperature of the air or gas flow, as these may require special surface protection and special acoustic filler materials. The approximate insertion losses of a representative group of ventilation-duct mufflers are given in table 3-10. Individual suppliers can give data for their specific products.

Table 3-10. Approximate insertion loss (in dB) of various lengths of commercial duct mufflers.

Octave Frequency Band (Hz)	Low Pressure-Drop Class: Muffler Length			High Pressure-Drop Class: Muffler Length		
	3 ft.	5 ft.	7 ft.	3 ft.	5 ft.	7 ft.
63[a]	4	8	10	8	11	13
125	7	12	15	10	14	18
250	9	14	19	15	23	30
500	12	16	20	23	32	40
1000	15	19	22	30	38	44
2000	16	20	24	35	42	48
4000	14	18	22	28	36	42
8000	9	14	18	23	30	36

Refer to manufacturers' literature for more specific data.

[a] Insertion loss values usually are not measured and quoted for the 31-Hz octave band. For calculations, assume the 31-Hz insertion loss is about 60% of the 63-Hz insertion loss, rounded off to the nearest decibel.

d. Muffle self-noise. When air or gas passes through a narrow opening at high speed, noise is generated by the turbulence of the gas exiting from the opening. The noise made at the exiting end of a muffler is called "muffler self-noise." There is no precise schedule of self-noise as a function of exit speed for large mufflers, but the following rules-of-thumb for exhaust stacks of turbine engines are offered. For installations in relatively noisy situations or where moderate amounts of noise can be tolerated, the exit speed of air or gas can approach but should not exceed about 175 to 200 ft./sec. For critical acoustic situations, the exit speed should not exceed about 125 to 150 ft./sec. For hot exhausts, the exhaust gas is of lower density and consequently has a higher total volume flow for a given mass flow than would exist at normal ambient temperature. The manufacturers of duct mufflers can usually furnish self-noise data for their products.

e. Muffler pressure drop. In any installation where exhaust or inlet pressures are of concern, the designer should request the muffler manufacturer to provide pressure-drop data for the proposed mufflers, and these values should be checked and approved by the engine manufacturer.

3-5. Ventilation duct lining.

Duct lining is used to absorb duct-transmitted noise. Typically, duct lining is 1 in. thick. Long lengths of duct lining can be very effective in absorbing high-frequency sound, but the thin thickness is not very effective for lowfrequency absorption. The ASHRAE Handbook and Product Directory-Fundamentals (app. B) can be used to estimate the attenuation of duct lining. Lined 90 deg. square turns are very effective in reducing high-frequency noise. Turning vanes or rounded 90 degree turns, however, provides neglible amounts of high-frequency loss.

3-6. Vibration isolation of reciprocating engines.

Vibration isolation of reciprocating engine assemblies is discussed for two general locations: on an on-grade slab, such as in a basement or ground level locations, and on an upper floor of a multifloor building. Suggestions given here are based on acoustical considerations only; these are not intended to represent structural design requirements. These suggestions apply to both the engine and all attached equipment driven by the engine. It is assumed that the mechanical engineer, structural engineer, or equipment manufacturer will specify a stiff, integral base assembly for the mounting of the equipment and that all equipment will be properly aligned. The base assembly should be stiff enough to permit mounting of the entire equipment load on individual point supports, such as "soft" steel springs. Equipment installations that involve close-by vibration-sensitive equipment, instruments, or processes are beyond the generalized recommendations given here. The basics of vibration isolation (criteria, materials, and approaches) are given in chapters 4 and 9 of the N&V manual. The term "engine assembly" is use here to include the engine, all driven equipment (such as gear, generator, compressor, etc.), and the engine base. The term "engine base" is used here to include a stiff steel base or platform that supports the engine assembly and a concrete inertia block to which the steel base is rigidly attached.

a. Concrete inertia block. A concrete inertia block is required under each engine assembly unless stated otherwise. The concrete inertia block adds stability to the installation and reduces vibration. For reciprocating engine speeds under about 360 rpm, the weight of the concrete inertia block should be at least 5 times the total weight of the supported load; for engine speeds between 360 and 720 rpm, the inertia block should weigh at least 3 times the total weight of the supported load; and for engine speeds above about 720 rpm, the inertia block should weigh at least 2 times the total weight of the supported load. Even small inertia blocks should be thick enough to provide a stiff base for maintaining alignment of equipment when the inertia block is mounted on springs around the perimeter of the block. Additional vibration isolation details are given below as a function of location and engine speed and power.

b. On-grade location. The chart in figure 3-2 shows the paragraphs below that give recommended vibration isolation treatments for various combinations of engine speed and power rating.

[retrieve: Figure 3-2. Chart showing paragraph number in manual that contains vibration isolation recommendations for on-grade installations of reciprocating engines as a function of engine speed and power rating.]

(1) For engines under 600 rpm (for any size) and over 1200 hp (for any speed).

(a) No vibration isolation of the engine assembly is required if there is no category 1 area (table 3-2 in N&V manual) within a horizontal distance of 500 ft., or no category 2 or 3 area within 250 ft., or no category 4 or 5 area within 150 ft. of the engine base. It is good practice, nevertheless, to give the engine base its own footings, separated from the footings of the generator room, with a structural break between the floor slab or floor grille of the generator room and the engine base. (It is assumed throughout this schedule that feelable vibration is acceptable in category 6 areas. If this is not an acceptable assumption, category 6 should be considered along with categories 4 and 5.)

(b) For distances closer than those listed in (a) above, for the indicated categories, the engine base should be supported on steel spring vibration isolation mounts that have a static deflection of at least 1 in. for engine speeds above 600 rpm or 2 in. for engine speeds of 301 to 600 rpm or at least 4 in. for engine speeds of 200 to 300 rpm.

(c) The steel springs of (b) above should rest on pads of ribbed or waffle-pattern neoprene if the engine assembly is located within 200 ft. of a category 1 are or within 100 ft. of a category 2 or 3 area or within 50 ft. of a category 4 or 5 are. Pad details are given in paragraph d(1) below.

(2) For engines above 600 rpm and under 1200 hp (except (3) below).

(a) No vibration isolation of the engine assembly is required if there is no category 1 area (table 3-2 in the N&V manual) within 300 ft., or no category 2 or 3 area within 150 ft., or no category 4 or 5 area within 75 ft. of the engine base. It is good practice, nevertheless, to give the engine base its own footings, separated from the footings of the generator room, with a structural break between the floor slab or floor grille of the generator room and the engine base. (It is assumed throughout this schedule that feelable vibration is acceptable in category 6 areas. If this is not an acceptable assumption, category 6 should be considered along with categories 4 and 5.)

(b) For distances closer than those listed in (a) above, for the indicated categories, the engine base should be supported on steel spring vibration isolation mounts that have a static deflection of at least 2 in. for engine speeds of 600 to 1200 rpm or at least 1 in. for engine speeds above 1200 rpm.

(c) The steel springs of (b) above should rest on pads of ribbed or waffle-pattern neoprene if the engine assembly is located within 200 ft. of a category 1 area or within 100 ft. of a category 2 or 3 area or within 50 ft. of a category 4 or 5 area. Pad details are given in paragraph d(1) below.

(3) For engines above 1200 rpm and under 400 hp. A concrete inertia block is not required for this

engine speed and power combination, although it would still be beneficial if used. All other recommendations of (2) above apply to the installation. If the concrete block is eliminated, a substantial housekeeping pad should be provided under the engine assembly, and the engine assembly should be mounted on a steel frame that is stiff enough to permit use of individual steel spring isolators under the steel frame without introducing equipment misalignment.

c. Upper-floor location. It is strongly suggested that no reciprocating engine assembly be mounted on any upper floor location of a wood-frame building and that no reciprocating engine over 600 hp or under 1200 rpm be installed on an upper floor of a steel or concrete building. If an engine rated under 600 hp and operating above 1200 rpm is installed in an upper floor location in a building containing category 1-5 occupancy areas (table 3-2 of the N&V manual), the following suggestions should be applied.

(1) The entire engine assembly should be mounted rigidly to a concrete inertia block having a weight at least 3 times the total weight of the supported load. The concrete inertia block may be eliminated, if desired, for any engine of less than 100 hp that is located two or more floors away from a category 1 or 2 area, or that is not located directly over a category 3 area. If a concrete inertia block is used, it should be thick enough to assure stiffness and good alignment to the entire assembly. Its area should be at least as large as the overall area of the equipment that it supports. If the engine drives a refrigeration compressor that is connected directly to its evaporator and condenser cylinders, all this equipment should be mounted together onto the same concrete block. The bottom of the inertia block should rest at least 4 in. above the top of the housekeeping pad or the structure slab. If a Type 5 floatingfloor slab is involved (para 5-5e of the N&V manual), this 4-in. air space under the concrete inertia block should be covered with 2-in.thick low-cost glass fiber or mineral wool. The engine assembly is not to be mounted on the floating-floor slab. If a concrete inertia block is not used, a substantial housekeeping pad should be provided under the engine assembly, and the engine assembly should be mounted on a rigid steel frame that is stiff enough to be supported off the floor on individual steel spring isolators without introducing stability or alignment problems.

(2) The concrete inertia block or the stiff steel frame of (1) above should be supported off the structure floor slab with steel spring vibration isolation mounts having minimum 2-in. static deflection under load.

(3) Each steel spring should rest on a block of ribbed or waffle-pattern neoprene pads, as described in d(1) below.

(4) The structure floor supporting a reciprocating engine assembly should be at least 10-in. thick and made of dense concrete (140 to 150 lb/ft.+3+). Where possible, the engine should be located over primary or secondary beams supporting the structure slab.

(5) Proper airborne noise control must be provided between the engine room and all nearby occupied areas, as discussed in chapter 5 of the N&V manual.

d. Other general recommendations. The following general recommendations apply to all engine installations requiring vibration isolation.

(1) Ribbed or waffle-pattern neoprene pads should be made up of three or four layers of the material, giving a total thickness of approximately 1 in. of neoprene. The area of the pads should be such as to provide the surface loading recommended by the pad manufacturer. For critical locations, provision should be made to permit replacement of the pads after about 25 years, as the pad material may deteriorate by that time. An arrangement for providing layers of neoprene pads under a spring base is seen in figure 9-1 of the N&V manual.

(2) For an isolated engine assembly, there should be no structural, rigid connections between the engine assembly and the building proper. This includes piping, conduit, and ducts to and from the assembly.

(a) A long bellows-type thermal expansion joint in the exhaust piping meets this requirement, as does a flexible connection in the inlet-air ducting to the engine.

(b) Piping to the engine assembly may contain long flexible connections (length at least 6 times the outside diameter of the piping) that are not short-circuited by steel bars that bridge the flanges of the flexible connections; or piping may be used without flexible connections, if the piping is supported on vibration isolation hangers or mounts for a distance along the pipe of at least 200 pipe diameters. The vibration isolation hangers should have a static deflection of at least one-half the static deflection of the mounts that support the engine base. If steel springs are used in the pipe hangers, neoprene or compressed glass fiber pads should be in series with the springs.

(c) Electrical bus bars from the generator should either contain a 6-ft. length of braided, flexible conductor across the vibration isolation joint, or be supported from resilient hangers for a distance of about 50 ft. from the isolated assembly.

(3) Where steel springs are use, unhoused stable steel springs are preferred. If housed or enclosed springs must be used, special attention must be given to the alignment of the mounts so that they do not tilt or bind in any direction within their housings. Further, there should be some visual means to check the spring mount in its final location to be certain that binding or tilting does not take place.

e. Special situations. The recommendations given in paragraph 3-6 will provide adequate coverage for most typical equipment installations. However, general rules cannot cover all marginal and complex variations. For unusual installations or unfamiliar conditions, it is advisable to have the assistance of a vibration or acoustical consultant experienced with this equipment. Vibration problems are sometimes quite complex and unpredictable.

3-7. Vibration isolation of turbine engines.

Typically, the smaller gas turbine engine-generator sets (under 5 MW) are mounted, transported, and installed as complete assemblies on steel-frame "skidlike" structures, and the large gas turbine systems (over about 5 MW) are installed at the site on long, stiff steel-beam bases, which in turn rest on concrete footings or concrete mats. The turbine speeds are very high (typically 3600 to 6000 rpm, some up to 25,000 rpm), and the alignment of turbine, gear, and generator is critical. The absence of rotary unbalance at these speeds is mandatory; hence, there is little or nor vibration compared to the vibration of a reciprocating engine. The steel beams of the large turbine engine assemblies require their concrete footings for additional longitudinal stiffness and system alignment, so steel springs are not recommended as point supports along the steel beams unless the manufacturer specifically proposes such mounts for critical installations. Instead, it is suggested that the engines be separated from any critical areas by adequate distance. Distance requirements set by the airborne noise problem will probably assure the adequate distances needed for vibration control. For these same reasons, the large units (above 5 MW) should not be installed in upper-floor locations. The following recommendations apply to turbine engine installations.

a. On-grade locations.

(1) "Skid-mounted" engine-generators (under about 5MW).

(a) No vibration isolation of the assembly is required if there is no category 1 area within 200 ft., or no category 2 or 3 area within 100 ft., or no category 4 or 5 area within 50 ft. of the engine assembly. Table 3-2 in the N&V manual explains these category designations.

(b) If the engine must be located closer than the distances listed above, for the indicated categories, the skid-type base should be mounted on ribbed or waffle-pattern neoprene pads. The pads should be made up of at least three layers of material having a total thickness of about 1 in. (para 3-6d(1) above). Pipes, ducts, and conduit to the engine-generator set should either contain flexible connections or be supported from resilient hangers for a distance of at least 25 ft. from the assembly. The engine manufacturer must approve the isolation mounting of the assembly.

(2) "On-site-assembled" generators (over about 5 MW).

(a) No vibration isolation of these assembly is required if there is no category 1 area within 400 ft., or no category 2 or 3 area within 200 ft., or no category 4 or 5 area within 100 ft. of the engine assembly. Even greater distances are desirable.

(b) If the engine must be located closer than the distances listed above, for the indicated categories, special concern must be given to the installation; and an agreeable design must be devised and approved by both the engine manufacturer and a vibration engineer or acoustics consultant. Such a design requires detailed knowledge about the specific engine and engine base involved and cannot be covered by generalizations in this manual.

b. Upper-floor locations.

(1) Skid-mounted engine-generators (under about 5 MW). These installations should be vibration isolated in accordance with table 9-11 in the N&V manual. If gas turbine engines are used to drive other types of equipment, such as reciprocating or centrifugal refrigeration or gas compressors, the recommendations of tables 9-3 or 9-5 (whichever is most nearly applicable) of the N&V manual should be used.

(2) "On-site-assembled" generators (over about 5 MW). These units should not be installed on upper floor locations without the assistance of a vibration or acoustics specialist.

3-8. Vibration isolation of auxiliary equipment.

Ventilating fans, cooling towers, pumps, and compressors may also be involved with an engine-generator system. Vibration isolation of this auxiliary equipment should be in accordance with chapter 9 of the N&V manual.

3-9. Use of hearing protection devices.

Personnel working in engine-generator rooms are exposed to hazardous noise levels are defined by

DoD Instruction 6055.3. A brief summary of this document is given in paragraph 3-4d of the N&V manual. The use of approved ear plugs or ear muffs is mandatory for personnel in engine rooms during engine operation. Signs specifying the use of hearing protection devices should be placed at each entrance to the engine room. Typically, well-fitted ear plus or ear muffs have insertion loss values of about 15 to 20 dB in the 63- to 250-Hz bands, rising with frequency to about 25 to 35 dB in the 1000- to 8000-Hz bands. Poorly fitted devices may have only 10 to 15 dB insertion loss values. When used in series, ear plugs plus ear muffs can increase the IL by about 10 dB over that of either ear plugs or ear muffs alone.

3-10. Nondisturbing warning and paging systems.

Outdoor audible paging systems are frequently annoying to neighbors. Indoor paging or warning systems frequently are so loud that they contribute to the hearing damage problem, or they may be so quiet that they cannot be heard in a noisy engine room. Consideration should be given to the use of one or more of the following nondisturbing warning or paging systems: flashing lights (possible coded to convey special meanings), "walkie-talkies" for outdoor personnel, "beepers" paging systems for outdoor or indoor personnel, limited power and directivity for outdoor loudspeakers, and automatic shut-off of outdoor paging systems at nighttime.

3-11. Quality of analysis procedure.

A detailed acoustical evaluation brings together large amounts of data, each component of which is subject to small errors or unknowns. Paragraph 8-5 in the N&V manual discusses this situation as it relates to the quality of the final answer. In summary, it states that the data and procedures have been found to produce satisfactory results in many different situations and applications, but the unusual circumstances statistically can produce unexpected results. Unexpected results can be avoided or minimized by encouraging a slightly conservative approach in acoustical designs. Design decision arising out of the use of the data forms (app. A) are often based on the following four categories used to describe the relative reliability or confidence level of the acoustical design. The designer should weigh carefully the applicability of these four categories to any particular evaluation.

a. "Preferred". The design equals or surpasses the requirements of the analysis in all frequency bands.

b. "Acceptable". The design produces no more than the following noise excesses above the design goal: 4 dB in the 31-, 63-, and 125-Hz bands, 3 dB in the 250-Hz band, or 2 dB in all the higher frequency bands.

c. "Marginal". The design produces one or more of the following noise excesses above the design goal, in any or all frequency bands: 5 to 7 dB in the 31-, 63-, and 125-Hz bands, 4 to 6 dB in the 250-Hz band, or 3 to 5 dB in all the higher frequency bands.

d. "Unacceptable". The design produces noise excesses above the design goal that are higher in any frequency band than those values listed for "marginal" in c above. It is strongly recommended that an "unacceptable" design not be permitted.

CHAPTER 4
EXAMPLES OF SOUND ANALYSIS PROCEDURE

4-1. Summary of examples.

Two engine-generator installations are studied in sufficient detail to illustrate the versatility of the sound analysis procedure. The first installation is an on-grade power plant with two engine rooms, a control room, and some nearby office space in the same building. A variety of gas or diesel reciprocating engines drive the generators. On-base housing is located relatively close to the plant. The second installation is a single conventional packaged gas turbine engine generator with its vertical intake and exhaust stacks fitted with mufflers to meet the noise requirements of a nearby military base hospital. Both examples are fabricated only to illustrate the methodology of this manual; they do not represent proven structural or operating layouts.

4-2. Example of an on-grade gas or diesel engine installation.

a. Description of the power station. A power station, shown in figure 4-1, is to be located 1200 ft. from on-base housing.

[retrieve: Figure 4-1. Plan of on-grade power station used as example for sound analysis in paragraph 4-2 of manual.]

Engine Room No. 1 contains two engines and has space for a third. Each engine has a 3500-hp rating, operates at 450 rpm, and can use either natural gas or diesel fuel. These in-line engines are turbocharged, with approximately 15-ft.long in-take ducts to the air cleaners located out of doors, as shown. The engine exhausts are fed through 50-ft. pipes to "best grade" low-pressure-drop exhaust mufflers, also out of doors. Engine Room No. 2 contains one 900-hp V-12 engine that operates at 1800 rpm and one 1600-hp V-16 engine that operates at 900 rpm. Another V-16 engine may be added later in this room. The V-12 engine has a turbocharger that draws intake air directly from the room through an air filter chamber, and the V-16 engine is fitted with a Roots Blower that draws air from the room without benefit of a muffler intake arrangement. Engine combustion air is drawn into this room through a side wall opening that is to be fitted with a muffler if necessary. These engines are fitted with "best-grade" exhaust mufflers through 30-ft.-long exhaust pipes. Low-pressure-drop mufflers are used with turbocharged engines, and high-pressure-drop mufflers are used with the Roots Blower engines.

(1) Personnel access doors are provided between the Maintenance Shop and the Engine Rooms, emergency exit doors are provided in the south walls of the Engine Rooms, and large equipment-access roll doors are provided between the Engine Rooms and a large "Receiving, Storage, Transfer Room" across the south side of the building.

(2) The Offices and Lunch Room and Lounge at the north side of the building are partially protected from Engine Room noise by "buffer" areas: The Toilet and Locker Rooms protect the Lunch Room and Lounge, and the corridor protects the group of Offices.

(3) The Maintenance Shop and the second-floor Control Room overlooking the two Engine Rooms must be evaluated in order to determine the requirements for walls, doors, and windows common with the Engine Rooms, with special emphasis being given to the size and make-up of the viewing windows in order to achieve an acceptable "SIL" (speech interference level) condition in the Control Room because of the present and future engines in the two Engine Rooms.

(4) A Mechanical Equipment Room provides ventilation air for the Engine Rooms as the outside and inside air temperatures dictate. The Control Room and Offices are served by a separate system to eliminate the possible feed-through of Engine Room noise into the quieter parts of the building. The engine air inlet in the wall of Engine Room No. 2 is always open in the event of failure of the building ventilation system.

b. Sound level requirements.

(1) Engine Rooms. There are no current state-of-the-art developments that will reduce engine room noise to the nonhazardous levels of less than 85 dB(A), so personnel using these rooms must use hearing protection equipment (approved ear plugs or ear muffs) when their daily exposures exceed the allowable limits (para 3-4d of the N&V manual.

(2) Maintenance Shop. Sound levels here shall not exceed 84 dB(A), for purposes of hearing protection, and it is preferred that the speech interference level (SIL) due to Engine Room noise not exceed 60 dB when Engine Room doors are closed (para 3-2d of the N&V manual describes SIL).

(3) Control Rooms. Sound levels here shall not exceed 84 dB(A), and it is preferred that the SIL due to Engine Room noise not exceed 55 dB when all engines, existing and future, are in operation.

(4) Offices. Engine Room noise heard in the offices shall not exceed NC-40 levels when all doors are closed (para 3-2a of the N&V manual).

(5) On-base housing. Power plan noise shall not exceed NC-25 levels indoors at the base housing located about 1200 ft. to the east of the plant, when all exterior doors of the plant are closed.

c. Engine Room noise levels. DD Form 2304 is used to estimate the PWL of each engine. DD Form 2295 (Room Constant by Estimation Method.) is used to estimate the Room Constant of each room. DD Form 2296 (Mechanical Equipment Room SPL Caused by Equipment) and DD Form 2297 (Summation of All Equipment SPLs on One Wall or Surface of the MER.) are used to estimate the SPLs at the Engine Room walls that are common to the other rooms of interest (the Maintenance Shop, the Control Room, and the corridor separating the Offices from Engine Room No. 2).

(1) Engine PWLs. The accompanying filled-in copies of DD Form 2304 give the estimated PWLs of the three noise components of each of the three engine types involved here. Only the engine casing noise (Part A) radiates into the Engine Rooms. For identification, see figures 4-2 through 4-4 for samples.

[retrieve: Figure 4-2. PWL of 3500-hp diesel engine in Engine Room No. 1 (DD Form 2304).]

[retrieve: Figure 4-3. PWL of 900-hp diesel engine in Engine Room No. 2 (DD Form 2304).]

[retrieve: Figure 4-4. PWL of 1600-hp diesel engine in Engine Room No. 2 (DD Form 2304).]

(2) Room Constants.

(a) Engine Room No. 1 is 60 ft. by 40 ft. by 30 ft. high, and its full ceiling area is covered with a thick sound absorption material of NRC = 0.75 to 0.85 (para 5-3b of the N&V manual). All side walls are expected to be of 10-in. hollow-core concrete block, if this will satisfy the acoustic requirements. The viewing window between this Engine Room and the upper-level Control Room is to be 1/2-in.-thick safety plate glass, 18 ft. wide and 4 ft. high. The steel roll door to the Receiving Room is of 1/8-in.-thick steel, and its area is 10 ft. wide by 18 ft. high. All personnel doors to Engine Rooms are of fireproof metal construction.

(b) Engine Room No. 2 is similar to Engine Room No. 1 in all but the following differences: the room area is 50 ft. by 40 ft., the Control Room viewing window is 12 ft. by 4 ft., and the air intake vent on the exterior east wall is 6 ft. by 10 ft. with an expected 40 ft.+2+ fully open area.

(c) Room Constants for the two Engine Rooms are estimated with the use of DD Form 2295. Figures 4-5 and 4-6 show the filled-in data forms for these two rooms.

[retrieve: Figure 4-5. Room Constant for Engine Room No. 1 (DD Form 2295).]

[retrieve: Figure 4-6. Room Constant for Engine Room No. 2 (DD Form 2295).]

(3) SPLs in Engine Room No. 1.

(a) Engine Room No. 1 will ultimately have 3 engines and 3 generators. Figure 4-2 gives the PWL of one engine, and tables 7-28 and 7-29 of the N&V manual gives PWL data for a generator. A 3500-hp engine would drive a generator with a rating of about 2.4 MW. The generator is direct-coupled to the engine, and would be driven at 450 rpm. Table 7-28 of the N&V manual indicates an overall PWL of about 105 dB for a generator of this speed and power. The PWL of the engine casing is 123 dB (from fig. 4-2), so it is clear that the engine is the controlling source and the generator can be ignored.

(b) DD Form 2296 is used to estimate the SPL in the engine room that impinges on the wall that is common to the Maintenance Room (lower level) and Control Room (upper level). Item 1 in this data form requires the SPL of the engine at a 3-ft. distance. When the PWL of an engine (from SPL fig. 4-2) and in a room (as given by para 5-3g, eq. 5-3, and table 5-7 in the N&V manual), are known, it is possible to calculate the SPL of the engine at the desired 3-ft. distance. For this large engine, it is somewhat fictitious to have an SPL that is 3 ft. from the acoustic center of the source, but in concept the procedure is correct. Table 4-1 shows the steps used to obtain this SPL.

Table 4-1. Calculations of 3-ft. SPL of one engine in Engine Room No. 1.

Col. 1	Col. 2	Col. 3	Col. 4	Col. 5
Octave Frequency Band (Hz)	PWL of Engine Casing (dB)	Room Constant of Engine Room No. 1 (ft+2+)	REL SPL From Table 5-7 (dB)	SPL at 3 Ft. Distance (dB)
31	111	660	- 8	103
63	111	810	- 8	103
125	117	1080	- 8	109
250	118	1620	- 9	109
500	116	2160	- 9	107
1000	114	2700	-10	104
2000	111	2700	-10	101
4000	105	2700	-10	95
8000	95	2700	-10	85

Column 2 gives the PWL of the engine casing (from Part A of figure 4-2), column 3 gives the Room Constant (from fig. 4-5), and column 4 gives the REL SPL (from table 5-7 of the N&V manual) for the 3-ft. distance and the various R values of column 3. Finally, column 5 gives the SPL, as obtained from equation 5-3 of the N&V manual, which is

L+p+ = L+w+ + REL SPL,

where REL SPL is negative valued, as shown in column 4 of table 4-1. The 3-ft. SPL values are then inserted in Items 1 and 4 of DD Form 2296 (fig. 4-7).

[retrieve: Figure 4-7. SPLs in Engine Room No. 1 caused by nearest engine (DD Form 2296).]

In Item 4 of figure 4-7, Surface "A" is the Maintenance Shop wall, at a distance of about 10 ft. to the acoustic center of the nearest engine, and Surface "B" is the upper-level Control Room wall, at a distance of about 14 ft. to the acoustic center of the engine. Item 5 is filled in with the R values of figure 4-5. Item 6 is obtained from figure 5-1 of the N&V manual by taking the SPL reduction (going "down" on the graph) from the 3-ft. starting distance out to the 10-ft. and 14-ft. wall distances, along the lines representing the Room Constant values of the various octave bands. Thus, for R = 660 ft.+2+ (in the 31-Hz band), the REL SPL of figure 5-1 drops from about -8 dB at 3-ft. distance to about -11 dB at 10-ft. distance and at 14-ft. distance. Thus, the SPL reduction for Item 6 would be 3 dB (from -8 dB down to -11 dB) at 31 Hz. The SPL reduction increases gradually at the higher R values in the higher octave bands. Item 7 then gives the SPL estimated at the engine room side of the Maintenance Shop wall and the Control Room wall.

(c) The procedure of (b) above is somewhat tedious, although correct. The procedure can be shortened with certain adaptations of the data form. Figure 4-8 shows the simplified (and still correct) version.

[retrieve: Figure 4-8. SPLs in Engine Room No. 1 from source PWL data (DD Form 2296).]

PWL data are entered at Item 2, and Item 6 values for the distances and R values of interest are read directly from table 5-7 of the N&V manual. This shortened procedures is recommended when source

PWL data are given. The 1-dB differences that occur in some Item 7 values, between figures 4-7 and 4-8, are caused by interpolating or rounding off to the nearest integer. Either set of values could be considered valid.

(d) The two other engines to the left side of the Engine Room also contribute SPLs to the Maintenance Shop wall and the Control Room wall. Additional copies of DD Form 2296 should be filled in for each sound source; the Item 4 distances are 28 ft. and 30 ft., respectively, for the second engine and 48 ft. and 49 ft., respectively, for the third (future) engine. Octave band levels, in decibels, are added in accordance with the decibel addition procedures given in the N&V manual. The simplest form is repeated here.

When two decibel values differ by	Add the following amount to the higher value
0 or 1 dB	3 dB
2 or 3 dB	2 dB
4 to 9 dB	1 dB
10 dB or more	0 dB

(e) The total SPLs at the Engine Room side of the Maintenance Shop and Control Room walls are then summarized on DD Form 2297. Figure 4-9 is a filledin copy for the common wall with the Maintenance Shop.

[retrieve: Figure 4-9. Summation of Engine Room SPLs on wall to Maintenance Shop (DD Form 2297).]

The SPLs at the Control Room wall are about 1 dB lower than these in the 500through 8000-Hz bands. It is noted here that if there had been no sound absorption material in the engine room, the total SPLs of figure 4-9 would have been 1 dB higher at 125 Hz, 3 dB higher at 250 Hz, 4 dB higher at 500 hZ, and 6 dB higher at 1000 through 8000 Hz.

(4) SPLs in Engine Room No. 2. Figure 4-10 gives the SPLs of the 900-hp engine extrapolated to the three walls of interest--Maintenance Shop, Control Room, and Office Corridor. Figure 4-11 gives the SPLs of the first 1600-hp engine same three walls. The SPLs of the future 1600-hp engine are the same as those give in figure 4-11, even though the wall distances are slightly differ-

ent. The summation of the SPLs for the three engines on these walls are given in figure 4-12.
[retrieve: Figure 4-10. SPLs in Engine Room No. 2 caused by 900-hp engine (DD Form 2296).]

[retrieve: Figure 4-11. SPLs in Engine Room No. 2 caused by first 1600-hp engine (DD Form 2296).]

[retrieve: Figure 4-12. Summation of SPLs in Engine Room No. 2 (DD Form 2297).]

(5) Wall selection for Maintenance Shop. The planned walls between the Engine Rooms and the Maintenance Shop will be of 1010-in.-thick hollow-core concrete block, if this is found to be acceptable acoustically. Each of these walls is 40 ft. x 12 ft., and each has a metal fireproof door of 2-ft.+2+ area. Maintenance Shop sound levels due to full operation of both Engine Rooms must not exceed 84 dB(A), and a 60 dB SIL (corresponds approximately to an NC-60 criterion) is preferred, if reasonably attainable. The Room Constant of the Maintenance Room is determined from DD Form 2295 where the room dimensions are 40 ft. by 28 ft. by 12 ft. high. The ceiling has acoustic absorption [AIMA mounting type 1, 0.65 to 0.75 NRC range.]. The data form (not included here) reveals an 1100-ft.+2+ high frequency room constant (for 1000 through 8000 Hz) and low frequency values of 220, 220, 330, 550, and 880 ft.+2+ for the 31- through 500-Hz octave bands, respectively. A copy of DD Form 2298 (Transmission Loss Requirement for Common Wall or Floor-Ceiling Between Source Room and Receiving Room) is filled in for each Engine Room feeding noise to the Maintenance Shop. Figures 4-13 and 4-14 show that noise from Engine Room No. 1 will be acceptable in the 500 through 2000-Hz bands (the SIL bands), but noise from Engine Room No. 2 will exceed the desired level by about 5 dB in the 500-Hz band.

[retrieve: Figure 4-13. TL requirement for noise from Engine Room No. 1 to Maintenance Shop (DD Form 2298).]

[retrieve: Figure 4-14. TL requirement for noise from Engine Room No. 2 to Maintenance Shop (DD Form 2298).]

If this were a critical problem, a more careful analysis could take into account the wall sections occupied by the electric shafts (reducing the wall area and therefore reducing slightly the transmitted noise), and it could permit excess noise at the 500-Hz band as long as the arithmetic average of the SPLs of all three SIL bands does not exceed 60 dB. Also, if this were a critical problem, an 8-in.-or 10-in.-thick solid concrete block wall would exceed the requirements. It would be reasonable here to have the planned 10-in. hollow-core concrete block walls. The A-weighted sound level is well under the 84-dB(A) maximum limit.

(6) Wall selection for Control Room. This is a more critical situation because an SIL of 55 dB is desired. The wall area to each Engine Room is 30 ft. by 8 ft., excluding the electrical shafts. The wall facing Engine Room No. 1 has a 72-ft.+2+ viewing window (planned to be of 1/2-in. safety plate glass) and the wall facing Engine Room No. 2 has a 48-ft.+2+ viewing window. A hung acoustic tile ceiling is planned, and an additional side wall area of 500 ft. will be covered with sound absorption panels of NRC = 0.75 to 0.85. The Room Constant is first estimated, by using DD Form 2295 as shown in figure 4-15. The initial study of TL requirements is then carried out with DD Form 2298. This is shown in figures 4-16 and 4-17.

[retrieve: Figure 4-15. Room constant estimates for the Control Room (DD Form 2295).]

[retrieve: Figure 4-16. TL requirement for noise fom Engine Room No. 1 to Control Room (DD Form 2298).]

[retrieve: Figure 4-17. TL requirement for noise from Engine Room No. 2 Control Room (DD Form 2298).]

(a) In Item 10, Selection A of figure 4-16, it is found that the planned 3-0% area of 1/2-in. conventional plate glass and 70 percent wall area of 10-in. hollow-core concrete block will fail to meet the 55-dB SIL requirement by 9, 6, and 2 dB in the 500-, 1000-, and 2000-Hz octave bands. The TL+c+ of this combination is calculated in accordance with paragraph 54e of the N&V manual, using N&V tables 5-9 and 5-14 for the TL of the concrete lock and glass portion of the wall. In Section B, the glass area is reduced to 20 percent of the total wall are, and a double glass window is assumed (two sheets of 1/4-in. glass with a 6-in. air space; N&V table 5-15). This represents an improvement but is still weak in the 500-Hz band. Selection C shows that a special laminated safety plate glass (footnote 4 in N&V table 5-14) containing a viscoelastic damping layer between the glass sheets will do as well as the double glass window. Although the special glass is more expensive, it will probably be less expensive than the special mounting required for the double glass window. Thus, Selection C is favored.

(b) Figure 4-17 carries out the same type of analysis for noise from Engine Room No. 2. Here, however, use of the 20 percent area window made of the special laminated and damped safety glass fails to achieve the 55-dB SIL by 8, 4, and 3 dB in the three speech frequency bands. This is a serious deficiency, and it suggests that bold measures must be considered. Selection B is made up of a 20 percent area special double glass window of the damped laminated glass (1/2in. glass, 2-in. air space, 3/8-in. glass) set in a wall of 10-in. solid concrete block. Even this wall arrangement still has a 3-dB deficiency at 500 Hz, but it would be recommended as a slightly marginal solution.

(c) A more beneficial approach is to go back to figures 4-4 and 4-12 and observe that the Roots Blowers on the 1600-hp engines are the major causes of the 500-Hz sound levels. Packaged commercial duct mufflers (table 3-10) adapted to the input of the Roots Blowers would reduce noise levels in Engine Room No. 2 and would benefit all nearby work spaces. Possibly the engine manufacturer or a muffler manufacturer already has a retrofit attachment for reducing the blower noise. It is cautioned that the intake muffler must have a large enough open area to allow free flow of adequate air to the engine. The analysis is not reworked here to accommodate this modification, but this situation illustrates that noise control can come in different forms. The remainder of the analysis is carried out without the benefit of the Roots Blower muffler, but such a muffler would reduce several building design problems.

(7) Noise levels to the offices.

(a) The SPLs in Engine Room No. 2 are given at the bottom of figure 4-12 for the region beside the office corridor wall. The noise criterion for each of the offices on the other side of the corridor is NC-40, with the doors closed. The partitions between adjoining offices and the partitions between the corridor and the offices are made of standard gypsum board and stud construction. The acoustic tile ceilings of the offices and the corridor have an NRC value in the range of 0.65 to 0.75. The Room Constants for the corridor and for a typical office are estimated in figures 4-18 and 4-19. For this particular geometry, the lobby-like space to the left of the corridor is included in the corridor since it will influence the sound levels entering the left wall of the left office. If this were a very critical problem, the Room Constant of the corridor alone would be calculated and used with the sound transmission path from the Engine Room to the corridor and then to the office; and the Room Constant of the lobby space alone would be calculated and used with the sound transmission from the Engine Room to the lobby space and then to the left-side office through its left-side partition.

[retrieve: Figure 4-18. Room Constant for corridor and lobby space (DD Form 2295).]

[retrieve: Figure 4-19. Room Constant for office (DD Form 2295).]

(b) Two alternative approaches are available for estimating the noise reduction from the Engine Room to the office. The first approach (the more complicated one) is to consider that the corridor first receives the noise from the Engine Room and then transmits it to the office. The second approach (simpler but less accurate) merely treats the corridor as a double wall separating the Engine Room and the office. The first approach is evaluated first. Figure 4-20 shows the steps involved in estimating the SPLs in the corridor space (item 9) between the Engine Room and the office. This data form is used because the Engine Room wall already has been selected to be 10-in. thick hollow-core concrete block.

[retrieve: Figure 4-20. Sound transmission from Engine Room No. 2 to corridor (DD Form 2299). (Sound Transmission From Source Room to Receiving Room Through Common Wall or Floor-Ceiling).]

[retrieve: Figure 4-21. TL requirement for noise from corridor to office (DD Form 2298).]

A gypsum board partition is tested as Selection A in item 10. The TL for this "Type 1" partition is obtained from table 5-12 of the N&V manual. The TL of a 2in.-thick solid wood door (9% of wall area) is combined with the TL of the gypsum board (using para 5-4e and fig. 5-3 of the N&V manual), and the resulting TL is inserted as Selection B of item 10. This wall combination fails to meet the requirement by 1 dB in the 125-Hz band. However, this is considered an acceptable selection, because low-frequency structureborne and earthborne vibration may limit the low-frequency sound levels that can be achieved anyway. Also, the vary narrow (4-ft. wide) corridor leads to an inaccurate SPL estimate in the low-frequency region (where the corridor width is much smaller than the wavelength of sound). If lower SPLs in the office are necessary, the "Type 2" stud partition of the N&V table 5-12 would provide 6 to 8 dB lower levels via airborne paths in the low-frequency region.

(c) The second possible approach to obtaining the office SPLs treats the corridor simply as a double wall. The TL is not precisely known, but can be roughly estimated with the use of figure 5-5 of the N&V manual. A 48-in.-wide corridor would increase the TL (over a single wall of comparable weight) by about 10 to 15 dB in the low-frequency region and 30 dB or more in the high-frequency region--if there were no rigid structural ties joining the two walls of the double wall. The floor, ceiling, columns, etc. serve as structural connections, so these full amounts of TL improvement will not be reached. Even so, a rough estimate of the TL of this double wall structure can be made. First, the total surface weight of both walls is estimated to be about 64 lb/ft.+2+ (52 for the 10-in. hollow-core concrete block and 12 for gypsum board partition). The TL of a single wall of this total weight is approximately that of a 12-in.-thick hollow-core concrete block wall (from N&V table 5-9). It can be assumed that the TL improvement attributable to the 48-in. corridor width will be about 50 percent of the amount shown in the N&V table 5-5 (extrapolated to a 48-in. air space) at low frequency, rising to about 90 percent of the amount shown in that table at high frequency. However, because of high-frequency sound leakage and flanking paths, it is doubtful that actual TL values would go much above about 70 dB for this particular structure. The resulting TL estimate is shown in item 6 of figure 4-22.

[retrieve: Figure 4-22. Sound transmission through double wall from engine Room No. 2 to Office (DD Form 2299).]

This simplified approach yields a "marginal" rating, whereas the more detailed analysis of figures 4-20 and 4-21 produces an "acceptable" rating for the same structure. The detailed approach is normally preferred because it takes into account the more specific design components, and, in this case, includes the influence of the sound absorption material in the corridor ceiling--which could just about eliminate the noise excesses that appear in item 12 of the figure 4-22 simplified analysis.

(d) A similar analysis carried out for the right-side office and the secretary's office would slightly lower sound levels because of the smaller wall area facing the corridor. Thus, any wall design that meets the acoustic requirement for the left-side office will be acceptable for all other spaces along the corridor.

(8) Vibration control for the offices. These offices are located only about 20 ft. from the nearest engines. This imposes fairly serious vibration isolation requirements to meet the NC-40 low-frequency sound levels in the offices. Paragraph 3-6 contains details of vibration isolation of reciprocating engines. The vibration isolation treatment should follow the recommendations given for a category 4 or 5 office or work space (N&V table 3-2) located within 20- to 80-ft. distances of the six large engines in this power plant. For such close distances, there is no guarantee that NC-40 levels can be reached in the low-frequency octave bands. Earthborne and structureborne vibration decays slowly with distance (N&V para 4-1), especially at low frequency. If this were a critical problem, it would be advisable to move the offices to greater distances from the power plant. In this sample problem, it is assumed that the office occupants are involved with the operation of the power plant and would be receptive to a moderate amount of noise and vibration.

(9) Engine exhaust noise to on-base housing.

(a) On-base housing is to be located 1200 ft. to the east of the power plant, and it is desired to not exceed NC-25 sound levels indoors at the housing. PWLs of muffled engine exhausts are given in figures 4-2 through 4-4. The top of each exhaust pipe extends above the roof of the power plant and is in unobstructed view of the housing. The PWLs of the six engine exhausts are given in table 4-2.

Table 4-2. Total PWL of the muffled exhausts of six engines in the figure 4-1 power plant.

Col. 1	Col. 2	Col. 3	Col. 4	Col. 5
Octave Frequency Band (Hz)	PWL 3500-hp, 3 engines (dB)	PWL 1600-hp, 2 engines (dB)	PWL 900-hp, 1 engine (dB)	Total PWL (dB)
31	---	---	---	---
63	112	113	106	116
125	113	115	107	118
250	111	111	105	115
500	105	105	99	109
1000	102	103	96	106
2000	97	93	91	101
4000	88	89	82	92
8000	80	81	74	84

+--+

The PWL contributions are obtained from Item 21 in figures 4-2, 4-3, and 4-4. Where two similar engines are involved, 3 dB are added to the levels of one engine (as in col. 3, taken from fig. 4-4); and where three similar engines are involved, 5 dB are added to the levels of one engine (as in col. 2, taken from fig. 4-2). The total PWLs of all six engine exhausts are given in the last column of table 4-2. (Appendix B of the N&V manual describes "decibel addition.")

(b) SPLs inside the base housing are estimated with the use of DD Form 2302 (Estimated Outdoor and Indoor SPL at Neighbor Position Caused by an Outdoor Sound Source Whose PWL is Known). A sample calculation is given in figure 4-23.

4

[retrieve: Figure 4-23. Estimated indoor SPLs of power plant noise at base housing (DD Form 2302).]

Item 13 shows an indoor noise excess of 3 to 6 dB in the 125- to 1000-Hz octave bands. This would be rated as "marginal". If the NC-25 criterion is a justified choice, these noise excesses should not be permitted. A number of other factors could influence the decision. If the housing is exposed to other uncontrollable excess noise (such as nearby highway activity or base aircraft activity), power plant noise might not appear so noticeable. However, if the base is located in a very quiet suburban or rural area, with very little other noise, the power plant noise will be very noticeable. If the base is located in a very hot or very cold region, year-round, and the windows are kept closed most of the time, and if inside sources, such as air conditioners or central heating and cooling systems, are in nearly continuous use, external noise sources will not be as noisy when heard indoors. These various conditions could be used to support or justify adjustments to the NC criterion. In the present problem, it is assumed that such factors have already been considered, and the NC-25 selection is a valid choice.

(c) A CNR analysis should be carried out as a means of checking or confirming the expected reaction of the housed personnel to the power plant noise. The N&V manual (para. 3-3c) summarizes the procedure. Figure 4-24 shows the CNR grid upon which the outdoor power plant SPLs are plotted (taken from Item 8 of fig. 4-23). A noise level rank of "e" is obtained.

[retrieve: Figure 4-24. Outdoor power plant noise at the base housing, plotted on CNR grid.]

The N&V table 3-4 or figure 3-4 provides a means of determining the correction number for the background noise in the area. If background noise measurements can be made at the existing base, N&V figure 3-4 should be used; otherwise the background noise correction may be estimated by selecting the most nearly applicable conditions of N&V table 3-4. For this sample problem, a background noise correction of +1 is used. N&V table 3-5 is then used to determine other correction numbers applicable to the problem. The following corrections are here assumed:

Correction for temporal or seasonal factors	
Day and night	0
Summer and winter	0
"On" full time	0
Correction for character of noise	
No unusual sounds	0
Correction for previous exposure	
Some previous exposure and good community relations	0
Background noise correction	
From discussion above	+1

Total corrections	+1

The CNR (composite noise rating) is then e + 1 = F. The N&V figure 3-5 is used to estimate the expected community response, where base personnel are assumed to be the equivalent of "average residents." A CNR value of F indicates a strong reaction against the noise for the conditions assumed here. A noise reduction of about 10 dB would bring the reaction down to "sporadic complaints," which might be considered a reasonable condition. CNR values of C or D are often encountered in nonmilitary situations.

(d) On the basis of both indoor and outdoor power plant noise at the base housing, the above analyses strongly suggest the need for a 5- to 10-dB reduction of noise, with principal emphasis on noise control in the 125- to 1000-Hz frequency range.

(e) Several possibilities exist for reduction of the excess noise. If the base has a large land area and is not yet constructed, the power plant and the housing area can be moved farther apart. An increase in distance from 1200 ft. to 2000 ft. would give a 250-Hz noise reduction of 5 dB, and an increase in distance to 3000 ft. would give a 250-Hz noise reduction of 10 dB (from N&V table 6-4). As one alternative, the base housing can be designed and constructed to have higher TL walls and closed windows facing the power plant. This would reduce indoor SPLs but would not change the outdoor SPLs. If possible, other large buildings on the base could be used to shield the housing area from the power plant. Two feasible alternatives could be applied at the power plant. In one, special large-volume, low-pressure-drop mufflers could be used, either singly or in series, in the exhaust lines from the engines to provide greater insertion loss than is quoted in table 3-2 for the rather conventional grades of mufflers. Such mufflers have been used successfully with large engines located as close as 600 to 800 ft. from residential areas. As another alternative, an outdoor L-shaped barrier wall extending above the top of the exhaust pipe openings for the engines in Engine Room No. 1 could be built above the secondfloor Mechanical Equipment Room and the south wall of the Engine Room to give a beneficial amount of noise reduction for the exhaust of the three 3500-hp engines. The exhaust mufflers for the two 1600-hp engines could be specified and purchased to have a larger amount of insertion loss than assumed in the figure 44 analysis. The 900-hp engine is the quietest one of the entire group and may or may not need additional muffling, depending on the success of the other pursuits.

(10) Other engine noise to on-base housing.

(a) Turbocharger inlet noise for the three outdoor inlets of the 3500-hp engines should be checked for meeting the desired indoor and outdoor levels of the base housing. The PWLs of the unmuffled inlet of one such engine is given in Item 16 of figure 4-2. These levels should be increased by a dB (for three engines), then extrapolated to the 1200-ft. distance. The inlet openings are partially shielded by the power plant building, and the barrier effect of the building can be estimated. Absorbent duct lining in the air inlet ducts or dissipative mufflers at the intake to the air cleaners can be very effective at reducing the high-frequency tonal sounds of the turbochargers.

(b) Sound from Engine Room No. 2 can escape from the open vent on the east wall of this room and travel directly to the housing area. Figure 4-23 shows the principal steps in the analysis of this part of the problem.

[retrieve: Figure 4-25. Engine Room vent noise transmission to the housing area (DD Form 2302).]

The SPLs inside Engine Room No. 2 are approximately those shown in figure 4-12. The PWL of the noise escaping through the unmuffled vent is calculated from equation 7-18 of the N&V manual. This is given in Item 2 of figure 4-25, for the open vent area of 40 ft.+2+. A 3-ft.-long low-pressure-drop dissipative muffler (data from table 3-10) is first planned for the vent opening (Item 6 in fig. 425). The noise radiating from the open front of the muffler has a small amount of directivity increase toward the housing. If the opening could freely radiate its sound in all horizontal directions, there would be no special directional effect, and normal sound propagation would exist. However, the presence of the large-area east wall of the building acts as a baffle that keeps one-half of the sound from radiating to the west. Thus, the sound that would have gone to the west (if the building were not there), instead is reflected to the east. This doubles the PWL of the sound radiating to the east and a 3-dB increase is added at Item 7. Combining all the factors, Item 13 of the analysis shows that the vent will produce 2-dB excess indoor levels at the housing in the 500-Hz band. When added to all other noise coming from the power plant, the total excess could be even larger. Thus, a better design would be either a 5-ft.-long low-pressuredrop muffler or a 3-ft.-long high-pressure-drop muffler or some other acceptable combination available from a muffler supplier.

(c) Next, noise radiated from the exterior east wall of the building should be checked. Material from paragraph 3-2a and equation 3-3 are involved (L+w+ = L+p+ - TL + 10 log A-16). Figure 4-26 summarizes the calculations of the PWL of the noise radiated externally by the east wall of Engine Room No. 2.

Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6
Octave Frequency Band (Hz)	SPL Inside Engine Room (dB)	TL lO-in. Hollow Block (dB)	10 log A -16 (dB)	PWL of Radiated Wall-Engine Noise (dB)	PWL of Sum of Sources
31	96	31	15		
63	102	36	15	81	113
25	104	36	15	83	116
250	104	37	15	82	118
500	110	42	15	83	125
1000	108	46	15	77	125
2000	104	50	15	69	120
4000	98	54	15	59	114
8000	90	58	15	47	105

Figure 4-26. Estimated PWL of engine noise radiated from east wall of Engine Room No. 2.

Column 2 gives the SPL inside the Engine Room, as taken from figure 4-12. Column 3 gives the TL of the exterior wall of the building, 10-in.-thick hollow-core concrete block, from N&V table 5-9. Column 4 represents the term (10 log A-16), where the area of the east wall is 30 x 40 = 1200 ft.+2+ when the 40-ft.+2+ area of the muffled vent opening is neglected. Column 5 is then the radiated PWL of equation 3-3

(Column 5 = Column 2 - Column 3 + Column 4). In accordance with the caution of paragraph 3-2a, it should be determined that this calculated radiated PWL does not exceed the low-frequency PWL of the sources inside the room. This is done by comparing the Column 5 values with the sum of the engine casing PWLs of the three engines in Engine Room No. 2 (from fig. 4-3 and 4-4). This sum is shown in Column 6. It is clear that the Column 5 values are less than the Column 6 values. The Column 5 PWL is next extrapolated to the base housing with the use of figure 4-27.

[retrieve: Figure 4-27. Wall-radiated noise to the base housing (DD Form 2302).]

Comparison of the SPLs in Items 10 and 12 shows that the noise radiated by the wall will fall about 20 to 30 dB below the NC-25 indoor criterion levels. Thus, wall-radiated noise will be of no concern in this simple problem.

(d) Engine noise escaping through the room should be checked in accordance with paragraph 3-2d. The roof deck for the building is of 2-in. thick poured concrete on corrugated metal. The TL of the roof deck is estimated to be about the same as that of 2-in.-thick dense plaster (N&V table 5-11) or about 4 dB less than that of 4-in.-thick dense plaster (N&V table 5-11) or about 5 dB less than that of 4-in.-thick dense concrete (N&V table 5-8), whichever is less. Equation 3-3 is used here to obtain the PWL radiated separately by each Engine Room roof. Then, the directivity loss in the horizontal direction is applied, using table 3-1. The power plant building has a parapet, so it qualifies as a Type 1 roof, and the smaller D dimension of each Engine Room is 40 ft., so the column of directivity corrections for "D under 50 ft." should be used. Each Engine Room has different sound sources, so the effect of each roof section must be calculated. Only one roof (for Engine Room No. 2) is illustrated in figure 4-28.

[retrieve: Figure 4-28. Roof-radiated noise to the base housing (DD Form 2302).]

Item 2 in the figure is the PWL of roof-radiate noise obtained with the use of equation 3-3, using the TL of 2-in. dense plaster and an area of 40 x 50 = 2000 ft.+2+ Comparison of Items 10 and 12 shows that roof-radiated noise is also about 20 to 30 dB below NC-25 indoor sound levels at the base housing.

(e) This completes the basic analysis of the community noise obtained from each noise source of group of noise sources considered in this sample calculation. One final check is required of the entire plant. When the analysis is completed on each individual source radiating toward the housing, and suitable noise control measures are tentatively selected for each source, a final analysis should be made of the entire plant. All sources together must not exceed the noise criterion in all octave bands. If a few sources combine to produce excessive noise in one or more octave bands, the noise control treatments for those sources in those octave bands should be improved sufficiently to eliminate the calculated noise excess completely. This final step in the total analysis should assure a satisfactory noise design for the complete installation.

4-3. Example of an on-grade packaged gas turbine generator plant.

The gas turbine generator plant plays an increasingly prominent role in out-ofthe-way locations for both continuous and peak-load applications. Its relative portability means that it can be moved in and set up almost anywhere power is needed, but, by the same token, its light weight makes it a potential noise problem. The gas turbine is basically a very noisy device, and the simple cabinet-like enclosure and the all-too-frequent shortage of adequate mufflers do not always control the noise.

a. Description of power plant. In this example, a 15-MW plant is supplied by the manufacturer in a packaged form as shown in figure 4-19.

[retrieve: Figure 4-29. Schematic arrangement of outdoor-type packaged gas turbine generator plant.]

This plant is to be located 1600 ft. from a military base hospital, and it is the designer's responsibility to specify the acoustic requirements of the packaged generator. The gas turbine power output haft, operating at 7200 rpm, drives a gear which in turn drives a generator at 3600 rpm. The Engine Room and the Generator Room are ventilated by 30-hp fans, as seen in the exhaust vents of these two rooms in figure 4-3. The manufacturer provides a housing for the entire unit that is made of 1/16-in.-thick sheet steel with a 4-in.-thick absorbent lining on the inside, covered with 22-gauge perforate sheet steel. Consideration should be given to the following parts of the noise problem: Muffler requirement and design for the air inlet to the engine, muffler requirement and design for the engine exhaust, noise escape from the walls and roof of the entire package, noise escape from the ventilation openings of the Engine and Generator Rooms, hearing protection for operators, when necessary, and acceptable noise levels in the Control Room. In this sample problem, only the intake and exhaust muffler requirements are evaluated. Details of the other parts of the total study would follow along the lines of the example given in detail in paragraph 4-2.

b. PWL criterion for noise to hospital. It is first required to estimate the total PWL of the power plant that will just produce acceptable sound levels inside the hospital building at a distance of 1600-ft. An indoor criterion of NC-20 for patient rooms is wanted. This low level is selected to help reduce the audibility of the tonal sounds of the plant. The hospital is fitted with sealed-closed windows, with each room receiving some fresh air through small wall vents to the outside (similar to wall type C in the N&V table 6-10). There is a tall growth of medium dense woods between the power plant and the hospital. The woods are about 500 ft. deep, and the trees are about 40 ft. high. The top of the exhaust stack of the power plant is about 30 ft. above ground elevation, and the upper windows of the two-floor hospital buildings are about 25 ft. above ground. The approximate insertion loss of the woods is estimated with the use of DD Form 2300 (Elevation Profile Between Sound Source and Receiver Position) and DD Form 2301 (Estimation of Insertion Loss of Vegetation in Outdoor Sound Path). Figures 4-30 and 4-31 are filled-in copies of these two data forms.

[retrieve: Figure 4-30. Elevation profile showing wooded area between power plant and hospital (DD Form 2300).]

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[retrieve: Table 4-31. Estimated insertion loss of woods shown in figure 4-30 (DD Form 2301).]

[retrieve: Figure 4-32. Calculation of PWL criterion, made by using this data form in reverse order (DD Form 2302).]

The NC-20 acceptable indoor sound levels are first inserted in Items 11 and 12. If the criterion levels are met, the Item 10 values will be the same as the Item 12 values, so they are repeated in Item 10. Item 9 shows the noise reduction of outdoor noise coming indoors through the wall, which most nearly resembles wall type C of the N&V table 6-7. The allowable outdoor noise levels (Item 8) are then the algebraic sum of Items 9 and 10. In traveling to the hospital, the sound encounters the wooded area evaluated figures 4-30 and 4-31. For a conservative estimate (lower value) of the insertion loss of the woods, the winter insertion loss from figure 4-31 is used in Item 5 of figure 4-32. Item 4 of figure 4-32 is the algebraic sum of Items 5 and 8. This "tentative outdoor SPL" would have been the same as the Item 8 values if there had been no woods. Item 3 is the distance term (N&V table 6-4 for standard-day sound propagation conditions) for the 1600-ft. distance (Item 1). Finally, Item 2 is the algebraic sum of Items 3 and 4. Thus, Item 2 represents the total PWL of the power plant sound that would just produce an NC-20 indoor criterion at the hospital--after traveling 1600 ft., passing through the wooded area, and entering the hospital through the type C wall structure. This is called the PWL criterion. In a reallife situation, the outdoor SPLs at the hospital (Item 8 of figure 4-32) probably would not be acceptable to residential neighbors. Further, the NC-20 criterion levels inside the hospital would not be achieved inside residences, at the same distances, that have their windows open much of the time. Thus, the problem developed here is based only on the conditions as defined.

c. PWL of engine sources. The three principal sources of a gas turbine engine are calculated with the use of DD Form 2305. The calculation is carried out for this 15-MW engine in figure 4-33.

[retrieve: Figure 4-33. Estimation of engine noise sources, first without specific intake and exhaust muffler details (DD Form 2305).]

The engine is housed inside the enclosure of the entire engine-generator package, which is assumed to have approximately the noise reduction of the type 5 enclosure of table 2-7. Both the air intake and exhaust stacks are oriented vertically and have the horizontal directivity effect shown for the 90 deg. angle in table 2-8. Each stack will be fitted with a muffler, whose insertion loss is still to be determined, but the muffler and the 90 deg. turn into the engine will provide at least a Class 1 lined bend (fig. 3-1 and table 3-9). If a longer muffler (greater in length than 1.5D in fig. 3-1) is later found necessary, this turn may qualify as a Class 2 lined bend, with a slight improvement in insertion loss. The tentative PWLs of the three sources are given in Items 6, 13, and 20 of figure 4-33, without the insertion losses of the intake and exhaust mufflers. In table 4-3, these three PWLs are added together and compared with the PWL criterion developed in figure 4-32.

Table 4-3. Summation of tentative PWLs of the three engine sources and comparison with the PWL criterion of figure 4-32.

Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7
Octave Frequency Band (Hz)	PWL of Enclosed Casing (dB)	PWL of Unmuffled Inlet (dB)	PWL of Unmuffled Exhaust (dB)	Sum of PWLs (dB)	PWL Criterion (dB)	Noise Reduction Required (dB)
31	110	119				
63	112	118	131	131	129	2
125	113	116	130	130	120	10
250	113	113	127	127	116	11
500	112	112	122	123	112	11
1000	111	115	117	120	112	8
2000	110	116	111	118	113	5
4000	109	113	104	115	122	---
8000	108	106	94	110	134	---

The last column in table 4-3 shows the amount of noise reduction required for the total plant to meet the criterion PWL. If in any given octave band all three engine components contribute significantly to the total noise, some of the sources must be quieted more than the column 7 amount, so that the total of the three components does not exceed the column 6 criterion. This point is illustrated by looking at the 500-Hz values, for example. If each source alone is quieted to just meet the 112-dB criterion value, the total of the three quieted components would be 117 dB, or 5 dB above the criterion level. Thus, the three sources must be quieted to such an extent that their new total ("decibel sum") will just equal 112 dB. From table 4-3, it is seen that the engine exhaust is clearly the dominant source in the 31- through 500-Hz octave bands, the engine intake noise exceeds the exhaust noise in the 2000- and 4000-Hz bands, and the engine casing noise is fairly close to the PWL criterion in the 250 through 2000Hz bands. This implies that all three sources may have to be quieted for the entire plant to meet the criterion.

d. Mufflers for engine intake and exhaust.

(1) Table 4-3 shows that the engine exhaust will require a muffler that should have insertion loss values of at least 2 dB at 63 Hz, 10 dB at 125 Hz, and
11 dB at 250 and 500 Hz, at an elevated exhaust temperature of about 1000 deg. F. The intake muffler should have insertion loss values of about 2 or 3 dB at 125
Hz, about 3 to 5 dB at 250 Hz, and about 5 to 10 dB in each of the 500- through 2000-Hz bands. Tables 3-3 through 3-8 may be used to approximate the dimensions
of mufflers that would yield these insertion losses. At 1000 deg. F

exhaust temperature, the speed of sound would be about 1870 ft./sec (from equation 2-1 in the N&V manual), which is about 1.7 times the speed of sound in air at normal temperature, assuming the exhaust gases are made up largely of the normal contents of air. This means that the exhaust muffler should be about 1.7 times longer than it would have to be at normal temperature to produce the same insertion loss.

(2) Table 3-6 offers a reasonable design for the exhaust muffler: 8-in.-thick parallel baffles separated by 8-in.-wide air spaces. The 8-ft. length exceeds the insertion loss requirement in all the octave bands, but by only 1 dB in the 125-Hz band. A 7-ft. length (at normal temperature) would very nearly meet the 10-dB requirement at 125 Hz. For the elevated temperature, the length should be increased to about 12 ft. (7 x 1.7 approximately). The cross-section area of the exhaust muffler must be large enough not to generate excessive back pressure and muffler self-noise.

(3) Table 3-3 offers a reasonable design for the intake muffler: 4-in.-thick parallel baffles separated by 12-in.-wide air spaces. An 8-ft. length of such design will meet the desired insertion loss values in all bands. This length will help the intake stack qualify as a class 1 lined band (a 4-ft.-length muffler would not be long enough; fig. 3-1); and the relatively large percent of open area will minimize inlet pressure drop.

(4) Table 4-4 summarizes the sound power levels of the three engine components with these mufflers installed. Comparison of the inlet and exhaust PWLs of tables 4-3 and 4-4 (col. 3 and 4) shows the amount of insertion loss assumed for the mufflers.

Table 4-4. Summation of PWLs of engine source, including muffled intake exhaust, and comparison with the PWL criterion of figure 4-32.

Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7
Octave Frequency Band (Hz)	PWL of Enclosed Casing (dB)	PWL of Muffled Inlet (dB)	PWL of Muffled Exhaust (dB)	Sum of PWLs (dB)	PWL Criterion (dB)	Noise Reduction Required (dB)
31	110	119	127	128	---	---
63	112	117	127	128	129	---
125	113	113	120	121	120	1
250	113	105	109	115	116	---
500	112	96	96	112	112	0
1000	111	96	93	111	112	---
2000	110	103	92	111	113	---
4000	109	103	88	110	122	---
8000	108	99	81	109	134	---

A 1-dB excess of noise still appears in the 125-Hz band, but the total design appears well balanced over the 63- through 2000-Hz bands.

(5) The insertion loss values used in this study and given in the chapter 3 tables are intended for

information and guidance only. As stated in paragraph 34a, muffler manufacturers should be consulted on the design and performance of their mufflers.

e. Other aspects of this sample problem. In a above, several parts of the total noise problem were listed, whereas only the inlet and exhaust mufflers have been evaluated here. In a total study, the SPL inside the Engine Room should be estimated (Room Constant and engine casing PWL are required), and the PWL radiated by the external shell of the housing should be calculated (as in para. 3-2). In the muffler analysis above, the noise reduction of the housing was merely estimated from its similarity with the type 5 enclosure of table 2-7. The noise of the gear and generator in the Generator Room should also be estimated (from chap. 7 tables in the N&V manual), and the noise escaping outside and through the two walls to the Control Room should be evaluated and compared with the applicable criteria. For both the Engine Room and the Generator Room, the escaping noise through the ventilation openings should be checked (including the noise of the 30-hp fans), and the insertion losses of the wall- and roof-mounted mufflers estimated. The total noise from all sources must be kept at or below the PWL criterion evaluated in figure 4-32. The external side walls of the intake and exhaust stack must have adequate TL (transmission loss) so that noise does not escape through these side-wall flanking paths. The TL of the side walls should be at least 10 dB greater than the insertion loss of the muffler (para. 3-4a). Finally, for conservation of hearing, personnel should be admitted into the Engine Room and Generator Room only when wearing adequate hearing protection, possibly consisting of both ear plugs and ear muffs. SPLs inside the Engine Room may exceed 110 to 115 dB in the upper octave bands if the engines do not have noise-reducing covers. Suitable labeling of the noise-hazardous areas should be included in the design of the plant.

4-4. Summary and conclusions.

a. The specific examples illustrated in this chapter and the generalized applications given in the N&V manual show the various calculable steps involved in the analysis of a wide variety of noise problems and solutions. Some of the acoustic analyses are quite simple and straightforward, and the results are quite reliable. However, some of the analyses involve approximations and a few nonrigorous steps, and a few of these are included in the example--largely to demonstrate that such approaches must sometimes be taken when exactness is not possible.

b. Data forms are used freely throughout this and the N&V manual to show that they are simple to use, that they remind the user of many key steps in the calculation procedures, that they provide documentation of the rationale and data used to arrive at acoustic designs, and that they are sufficiently flexible to be adapted to slightly different conditions from those for which they were designed. Blank copies of the data forms developed for this and the N&V manual are reproduced in appendix A. These forms may be duplicated and used to analyze and document the various steps in acoustic designs covered by these manuals.

c. A dilemma that might be brought on by the manual is the impasse which could develop when manufacturers state that their equipment or sound control devices perform better acoustically than is assumed here. If this situation should arise, it is important to receive some form of guaranteed assurance in writing (accompanied by valid test data carried out by a reputable and disinterested organization) that the manufacturer will back up the claims.

d. The procedures used in these manuals have evolved over the past 20 to 30 years of applied acoustics in the United States and have been used successfully to evaluate and solve many types of noise problems. The data and procedures are recommended for use by engineers, architects, and planners of military installations as well.

APPENDIX A

DATA FORMS

A blank copy of each of the data forms prescribed in this manual (DD Forms 2304 and 2305) can be located in appendix A. For Army, DD Forms 2304 and 2305 will be reproduced locally on 8 1/2 inch by 11 inch paper. Copies to be extracted for local reproduction are located in appendix A of this regulation. For Navy and Air Force, copies are available through normal forms/publications supply channels. Appendix E, TM 5-805-4/AFM 88-37/NAVFAC DM-3.10 contains blank forms for DD Forms 2294 through 2303.

[retrieve: Figure A-1. DD Form 2304 (Estimated Sound Power Level of Diesel or Gas Reciprocating Engine Noise.)]

[retrieve: Figure A-2. DD Form 2305 (Estimated Sound Power Level of Gas Turbine Engine Noise.)]

APPENDIX B

REFERENCES

-- Government Publications

Department of Defense

DoD 6055.3 Hearing Conservation.

Department of the Army

TM 5-805-4 Noise and Vibration Control for Mechanical Equipment.

Non-Government Publication

American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc. (ASHRAE), 347 East 47th Street, New York, NY 10017.

Handbook and Product Directory, Fundamentals. (1977)

APPENDIX C

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